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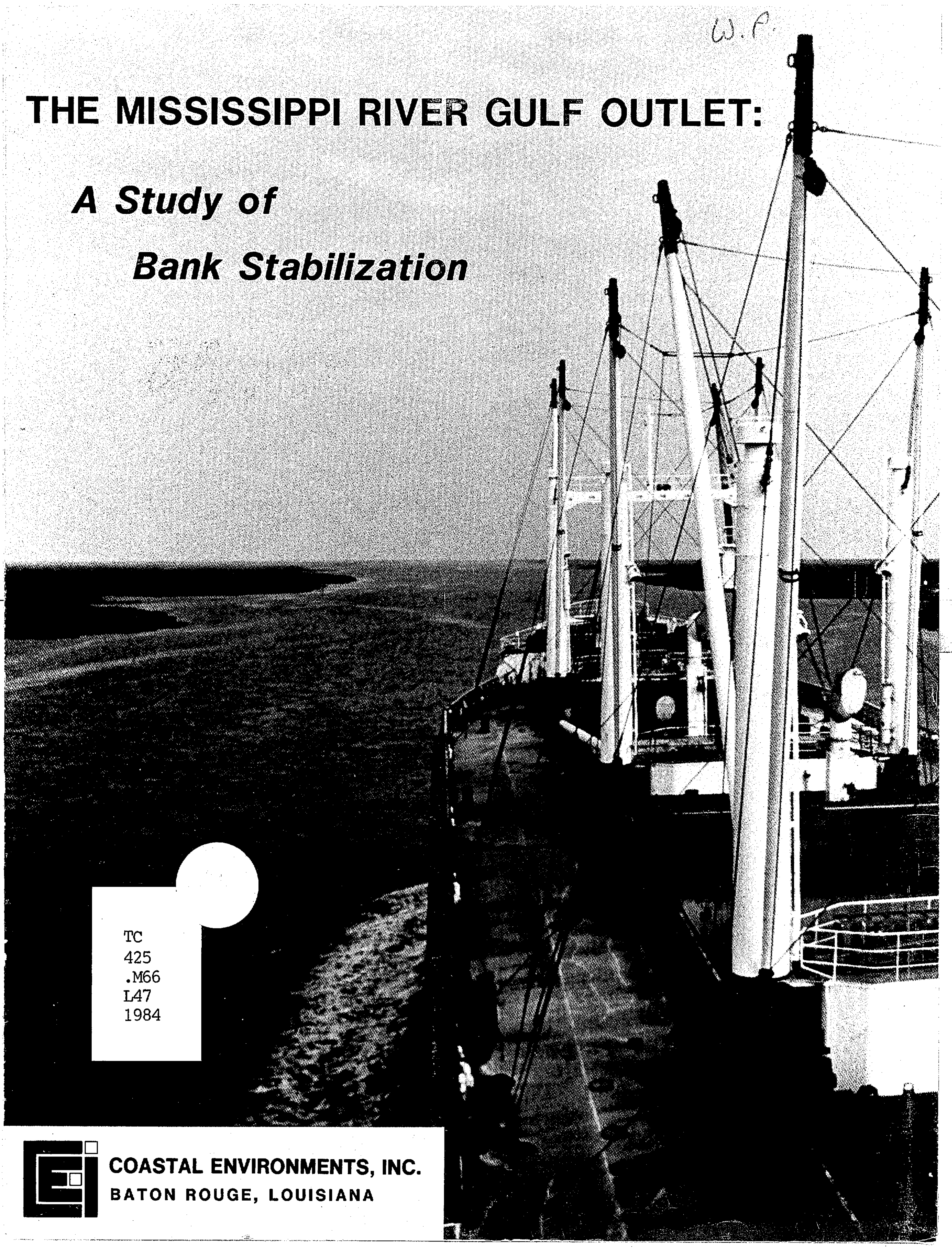
THE MISSISSIPPI RIVER GULF OUTLET:

A Study of Bank Stabilization



COASTAL ENVIRONMENTS, INC.
BATON ROUGE, LOUISIANA

THE MISSISSIPPI RIVER GULF OUTLET:
A STUDY OF BANK STABILIZTION

by

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December 1984

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CHAPTER 1: INTRODUCTION

The Mississippi River Gulf Outlet (MRGO) is a 76-mi-long, man-made waterway that extends from the City of New Orleans to the Gulf of Mexico. This ship canal was authorized by the U.S. Congress in 1956, and was undertaken as a full-scale project in 1958. Most of the canal was built through the ecologically sensitive wetlands of St. Bernard Parish during an era of low environmental awareness. The project brought on a litany of environmental problems, including habitat change, marsh loss, and severe shoreline erosion. These problems evolved immediately following construction, and are continuing largely unabated to this day. The 1970s brought a period of environmental awareness; consequently, many reports from individuals, private corporations, universities, and some governmental agencies have addressed numerous environmental impacts associated with the MRGO. The U.S. Army Corps of Engineers (USACE), the Federal agency responsible for design and construction of the MRGO, has only recently recognized MRGO-related problems. They have finally characterized the MRGO as one of eight areas in south Louisiana where "erosion stabilization measures are urgently needed" (USACE 1984).

The northeast shore of the MRGO has not yet received any stabilization measure to protect the sensitive marshes from either saltwater intrusion or ship waves. This report specifically addresses 22.5 mi of the northeast shore, from Bayou Bienvenue to Bayou La Loutre, with the dual purpose of defining the processes of marshland degradation and proposing specific measures for shoreline protection.

As a comprehensive environmental study, this report is interdisciplinary in its approach. It covers a full range of factors influencing the region and incorporates such diverse subjects as geology, soils, hydrology, vegetation, dredging, vessel traffic, and ship waves. Further, the suggested shoreline protection measures proposed include all facets of the problem. Engineers, planners, and politicians alike will find value in this document when they forge ahead to implement solutions.

Chapter 2 is a comprehensive description of the physical setting of the St. Bernard wetlands both prior to and following MRGO construction. Chapter 3 addresses the man-made aspects of the canal itself: the history of construction, maintenance, and vessel traffic. Chapter 4 examines the complex environmental interactions between the processes introduced by the canal and the environmental reactions that have followed. Chapter 5 presents a series of suggested shoreline protection measures; and finally, Chapter 6 discusses the ramifications of each protection measure and the value of using the various measures combined.

CHAPTER 2: PHYSICAL SETTING

Location

The MRGO is a 36-ft-deep, 500-ft-wide ship channel that runs from the Inner Harbor Navigation Canal for 76 mi southeastward to the Gulf of Mexico (Figure 1). Forty-three miles of this canal fall within a "landcut" through low-lying marshlands, most of which are in St. Bernard Parish. This study focuses on 22.5 mi of this landcut, that which extends from Bayou Bienvenue (MRGO Station No. 370) to Bayou La Loutre (MRGO Station No. 1560) (Figures 2a and 2b). This study also specifically addresses the wetland environment on the northeast shore of this MRGO section, all the way to the Lake Borgne shoreline.

The wetlands found within this study area have been previously defined as three unique management units (Wicker et al. 1982): Bayou Bienvenue, Proctor Point, and Lower Procter Point. The northernmost management area, the Bayou Bienvenue Unit, is bound by the natural hydrologic boundaries of Bayou Bienvenue, the MRGO, Bayou Dupree (the narrow cut into Lake Borgne where Martello Castle lies), and Lake Borgne. Procter Point Unit, the largest of the three, is bound by the hydrologic boundaries of Bayou Dupree, the MRGO, Bayou Yscloskey, and Lake Borgne. Lower Procter Point Unit is bound by Bayou Yscloskey, the MRGO, Bayou La Loutre, Bayou St. Malo, and Lake Borgne. The total area within all three is 23,931 ac, which is comprised of 61% marsh, 26% open water, 12% MRGO Canal and adjacent eroded area, and 1% shrub and forest (based on 1978 environmental analysis by Wicker et al. 1982). Clearly, the study area is typified by three environments: a vast expanse of marsh; numerous intermingling water bodies; and the MRGO, which borders the southwestern boundary.

Geology

St. Bernard Delta

The region through which the entire MRGO cuts was for a considerable time in prehistory occupied by an open, relatively deep (30 to 150 ft deep) body of water--the Gulf of Mexico. Three thousand years ago, this body of water began to be influenced by the development of the St. Bernard delta-building phase of the Mississippi River

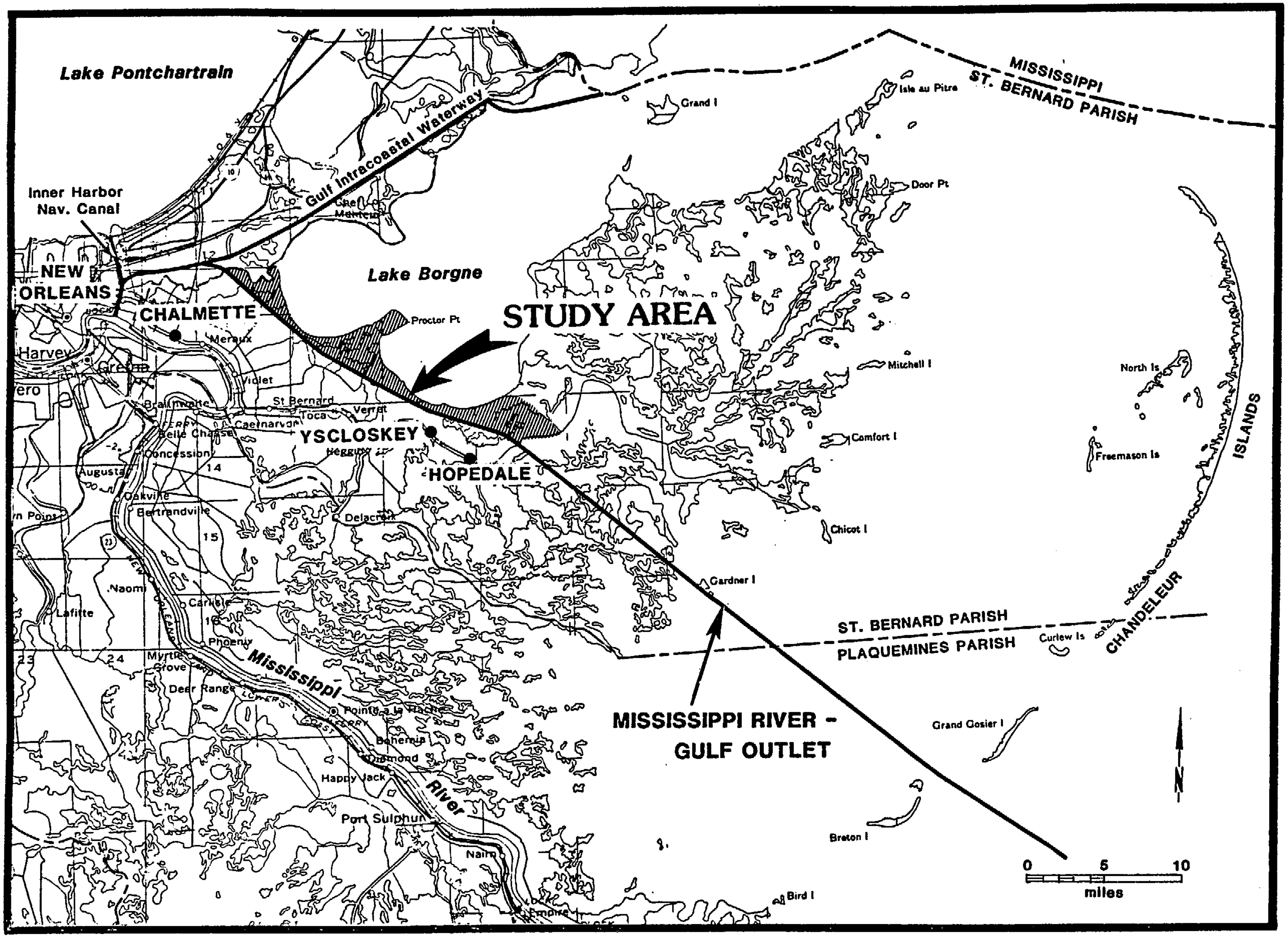

Figure 1. Study area location.

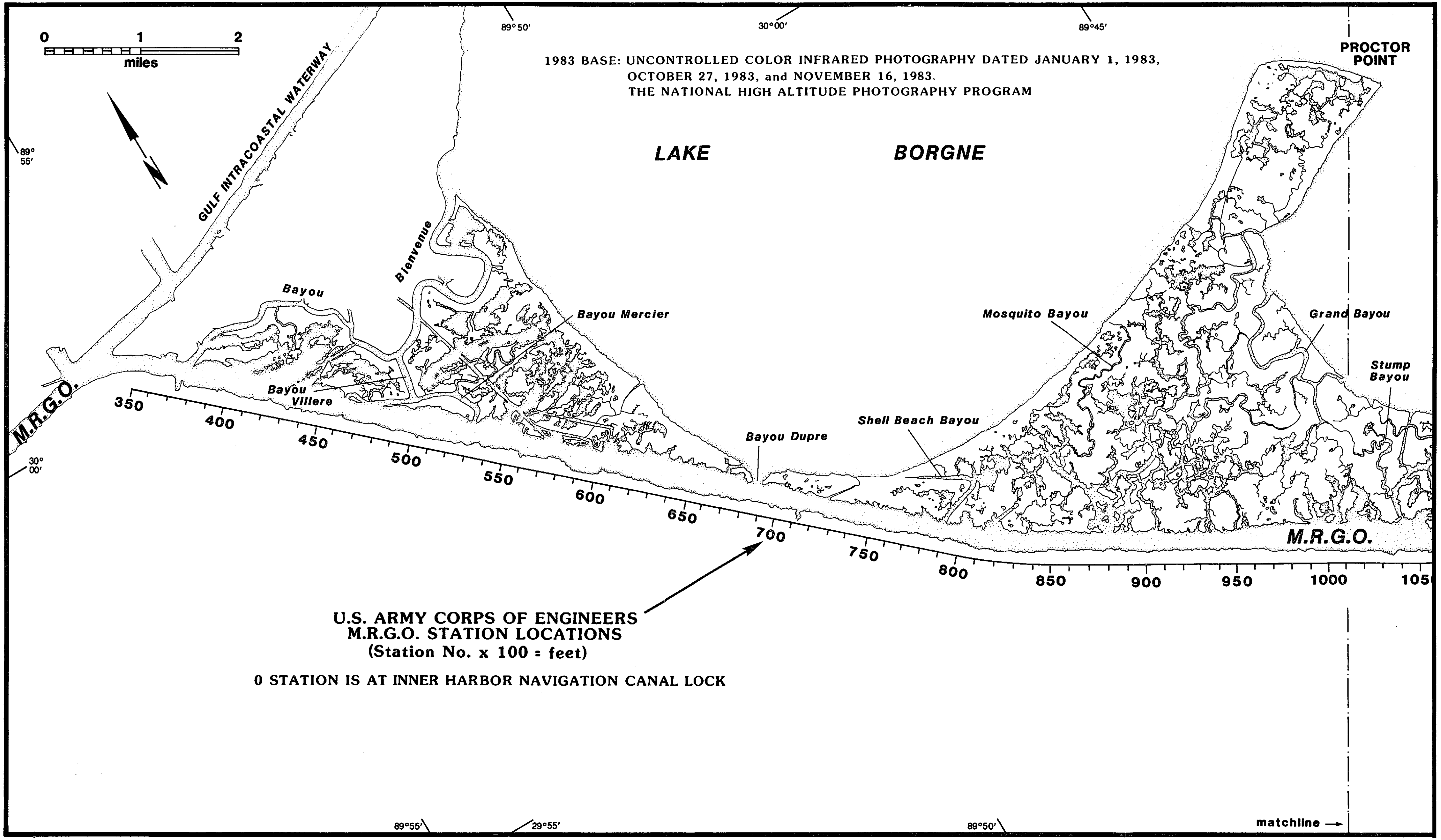

Figure 2a. Northeast shore of the MRGO and adjacent wetlands from Bayou Bienvenue to Bayou La Loutre.

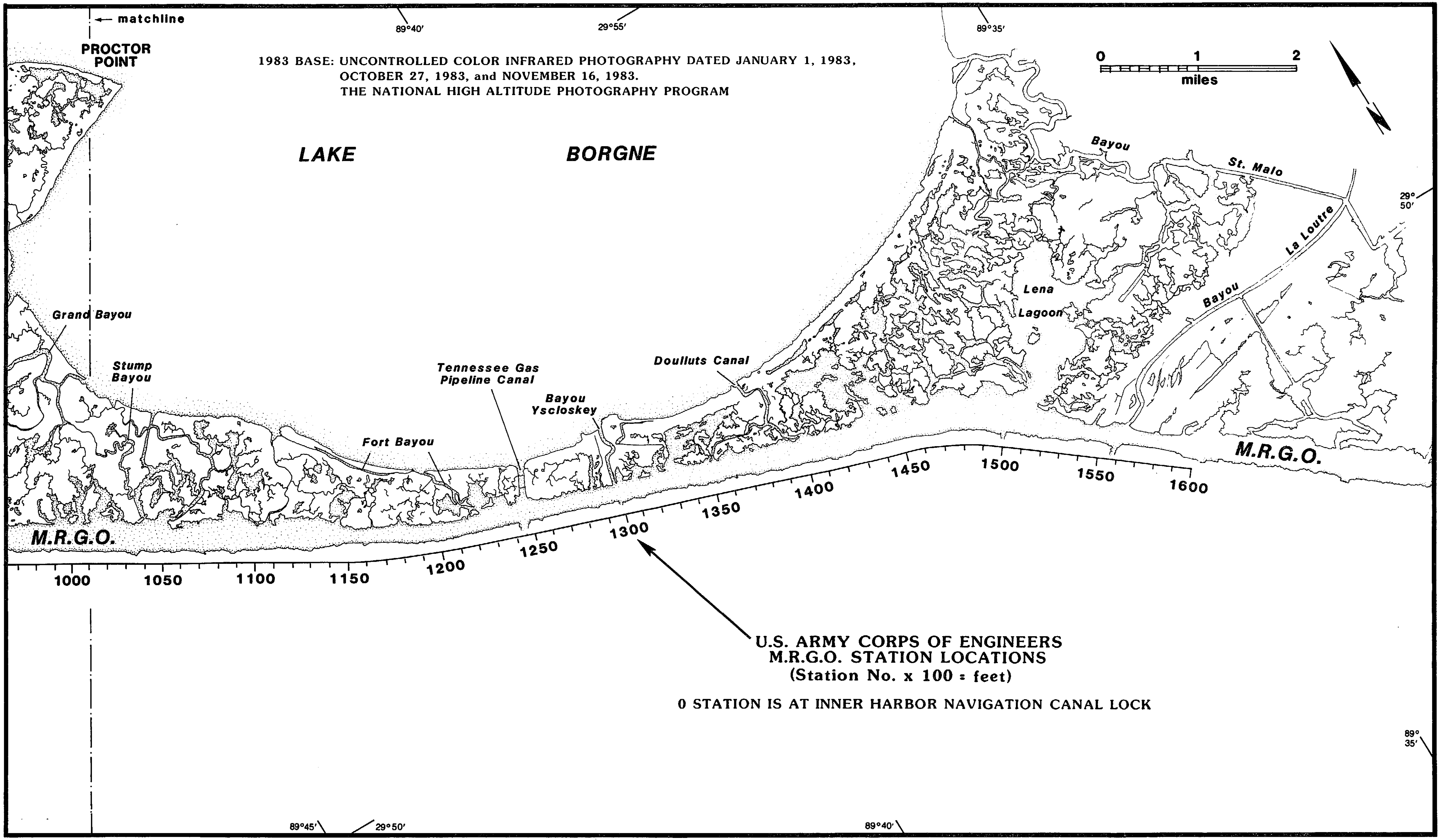

Figure 2b. Northeast shore of the MRGO and adjacent wetlands from Bayou Bienvenue to Bayou La Loutre.

system (Frazier 1967). At first, fine clays began settling in the region, blanketing the floor of the Gulf at an ever-increasing rate. This depositional episode preceded the advance of the subaerial portion of the St. Bernard delta. Clays, known as prodelta clays, formed to thicknesses as great as 100 ft, thus bringing the Gulf floor to a subuniform depth of 50 ft.

Deposition of prodelta clays continued in the distal reaches of the Gulf (beyond the present-day position of the Chandeleur Islands) for some time thereafter, but in the landward reaches (near New Orleans) fine sands and silts began to be deposited in brackish and fresh environments until they built to or above sea level. This formation comprises the interdelta environment, a complex interweaving of sediments deposited at the mouths of numerous advancing distributaries. Between the distributaries in the lower subaqueous basins, fine grained clays and lesser amounts of silts settled, forming what is known as interdistributary trough clays. This entire depositional system advanced rapidly gulfward through a very complex series of abandonment of small distributaries and advancement of newly formed distributaries. Some of these channels had considerable, prolonged flow, and thus remained as extensive, well developed systems. The present-day St. Bernard lobe still gives evidence of the major distributary locations, such as Bayou La Loutre, Bayou Terre aux Boeufs, and Bayou Yscloskey, which all rise above general marsh level with firm natural levee soil.

The St. Bernard delta building episode lasted for about 1,000 years, or until about 2,000 years ago (Frazier 1967). At its greatest extent, the landmass extended beyond the present location of the Chandeleur Island chain. At this time, Mississippi discharge began to flow in another, more western region of the Mississippi River deltaic plain; thus flow into the St. Bernard delta environment slowly, but surely, became reduced.

This "abandonment" signaled the beginning of the deterioration phase in the St. Bernard region. The seaward edge of the lobe began to be dominated by marine erosion through wave attack and tidal movement; therefore, land was lost and a barrier island system began to develop. Because of the lack of sedimentary input from distributaries, the ever-present process of subsidence began to dominate the system, and as the land fell, organic detritus constantly filled the interdistributary basins, thereby allowing for marsh and marsh substrate to form. Cessation of riverine flow allowed encroachment of saline sea water into the more seaward basins, thus killing swamps and fresh marshes. Brackish marshes, saline marshes, and open water bodies began to form.

The slow and orderly deterioration of the St. Bernard environment began 2,000 years ago and has continued until present day. Less than half of the original landmass remains; most of it has been replaced by Chandeleur Sound. The remaining landmass is to a great extent saline marsh interspersed with numerous bayous and bays. But there also are vast tracks of fresh marsh, brackish marsh, and fresh swamp in the more landward reaches of the region.

Major Depositional Types

The development of the St. Bernard delta has resulted in numerous depositional types through which the MRGO has been cut: prodelta, intradelta complex, interdistributary, natural levee, swamp, and marsh (Kolb 1958). Each of these types is presented in Table 1, shown in cross section on Figures 3a and 3b, and described below.

Prodelta

Prodelta clay comprises the great bulk of the sediment associated with the St. Bernard deltaic episode. It is the most deeply seated unit, found from 150 to 30 ft below sea level. The base of the MRGO channel cuts into this unit in a variety of locations (Figure 3a and 3b). Prodelta clay is a very homogeneous deposit comprised of 95% clay and 5% silt. Cohesive strength commonly ranges from 200 to 600 lbs/ft^2, which is relatively high when compared to most overlying deposits. Cohesion tends to increase with depth in these deposits because the lower layers have experienced greater consolidation under load.

Intradelta Complex

This unit is found in large pockets throughout the MRGO landcut. It generally ranges from 10 to 50 ft below sea level. Soil texture, on the average, is comprised of 35% clay, 40% silt, and 25% sand, although texture can actually have a considerable range both vertically and horizontally. Cohesive strength is judged as moderate, but it too can range considerably.

Table 1. Physical Characteristics of Depositional Types Found in the MRGO Landcut (Modified from Kolb 1958).

Depositional Type	Lithology	Natural Water Content Per Cent Dry Weight	Liquid Limit[1]	Plasticity Index[1]	Shear Strength(2)		Remarks
					Cohesive Strength (lb/ft^2)	Angle of Internal Friction in degrees	
Prodelta	95% Clay 5% Silt	40-80	70-120	30-55	200-600	0	Underlies entire deltaic sequence as homogeneous unit. Slopes and thickens toward the southeast.
Intradelta Complex	35% Clay 40% Silt 25% Sand	15-40	Non-plastic to 110	Non-plastic to 60	Moderate	Moderate	Relatively coarse portion of subaqueous delta. Intricately interfingered deposits. Disposed in broad wedges about abandoned courses and major distributaries.
Interdistributary	80% Clay 10% Silt 6% Sand 4% Organic	50-160	60-160	30-75	150-300	0	Disposed in clay wedges between major distributaries. Clay sequence interrupted by silty or sandy materials associated with myriad small distributaries, but otherwise fairly homogeneous. Material will probably displace laterally under fairly light load.
Natural Levee	55% Clay 40% Silt 5% Sand	20-40	Non-plastic to 75	Non-plastic to 30	800-1200	15-35	Disposed in irregular belts along abandoned courses and distributaries. Thickness averages 15 ft or less.
Swamp	75% Clay 5% Silt 20% Organic	60-200	60-150	30-60	Low	---	Relatively small areas.
Marsh	33% Clay 2% Silt 65% Organic	80-800	70-250	—	Very Low	—	Forms 90 per cent of land surface within study area. Average thickness 10 ft. Very high water content. Subject to rapid compaction under load.

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(1) Atterberg limits do not reflect water content of highly organic materials

(2) Cohesive strength of clays based on unconfined compression test

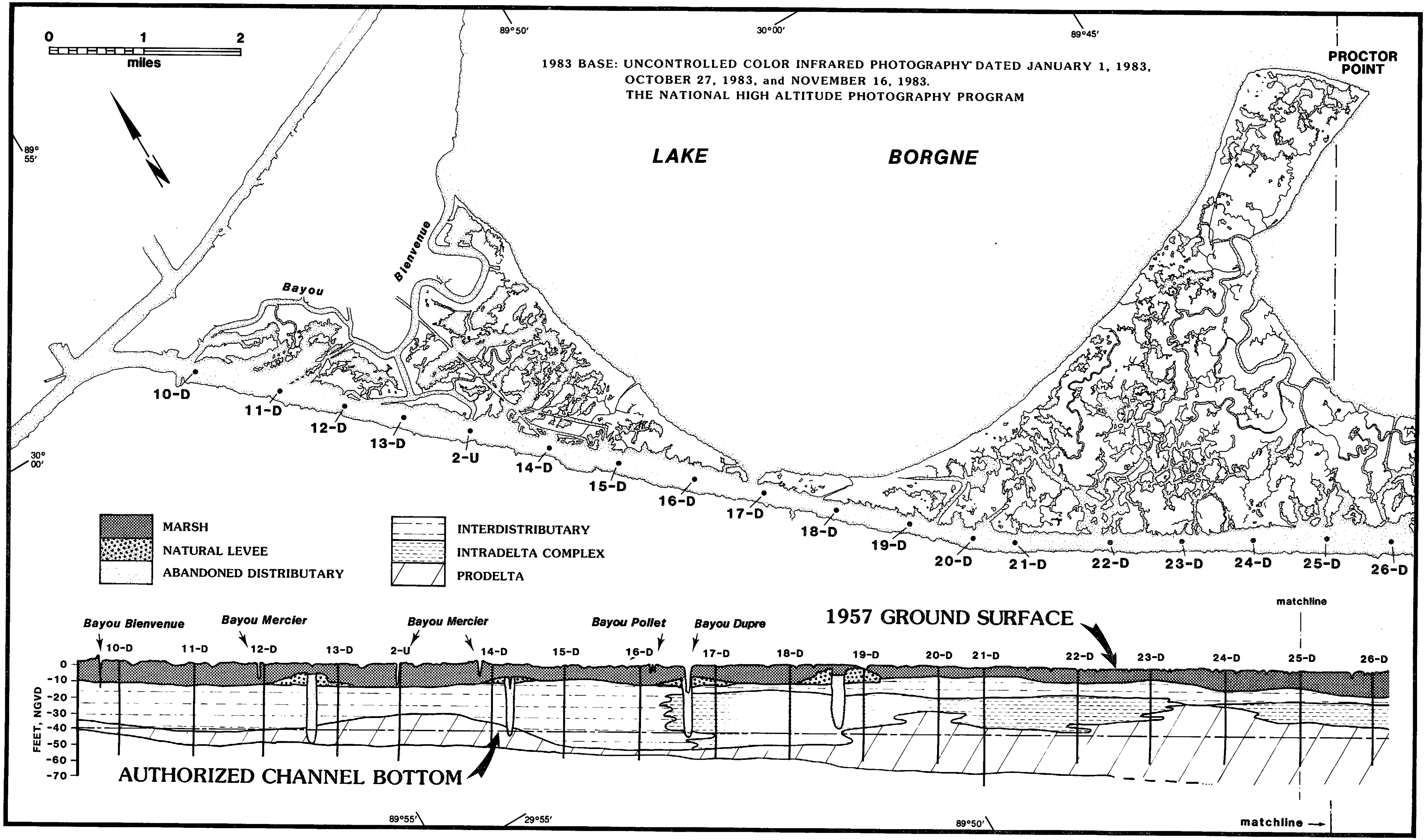

Figure 3a. MRGO subsurface geology (Kolb 1958).

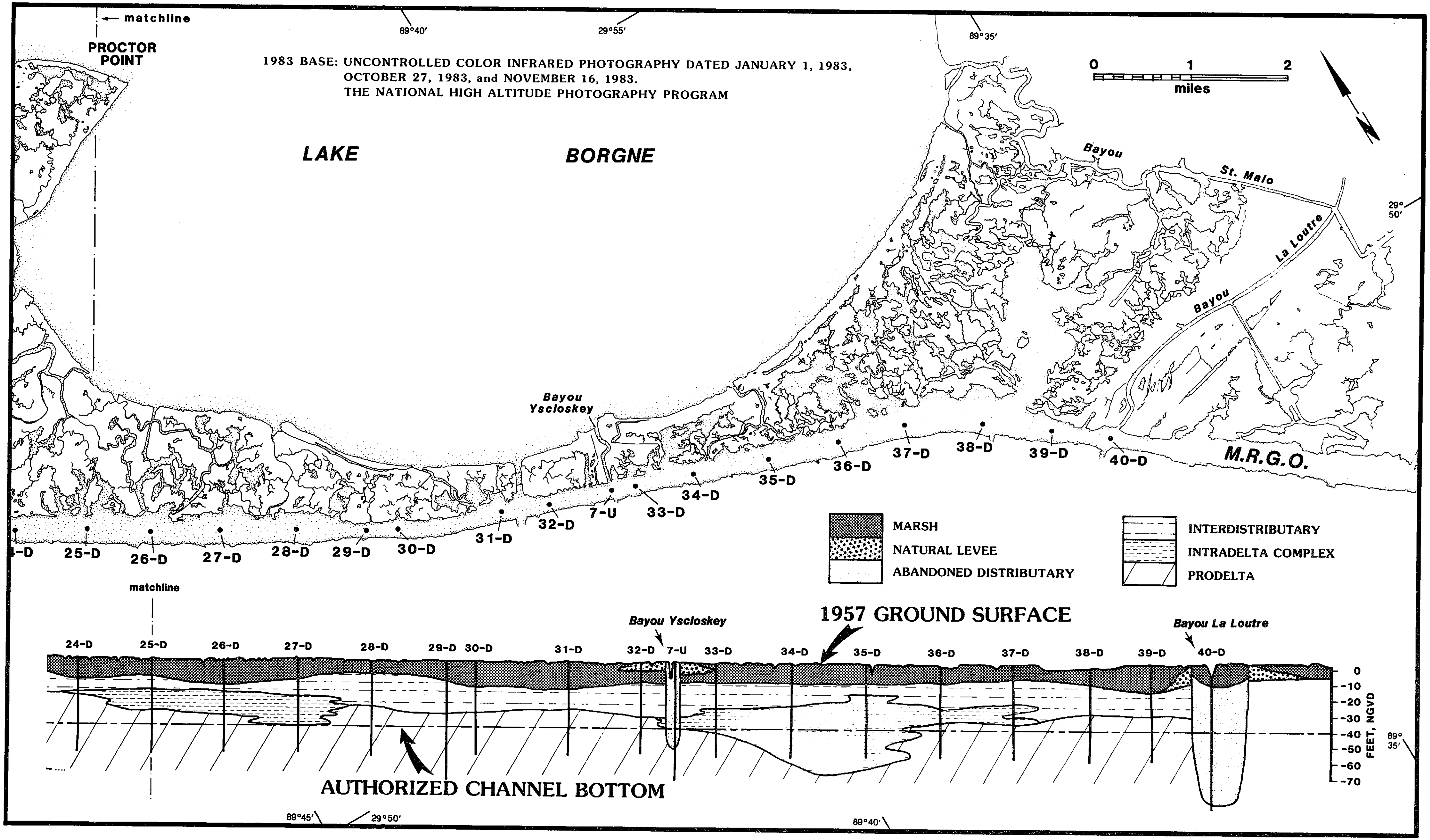

Figure 3b. MRGO subsurface geology (Kolb 1958).

Interdistributary

This unit is found in similarly sized and located patches as the intradelta complex. Much of the MRGO channel cuts through these deposits. Clay makes up 80% of the average unit. Cohesive strength ranges from 150 to 300 lbs/ft^2.

Natural Levee

These deposits are found in irregular bands flanking abandoned distributaries, such as Bayou La Loutre. Natural levees are generally silt and clay-rich with some minor sand. Cohesive strength ranges from 800 to 1200 lbs/ft^2. This is the highest cohesive strength of any deposit found in the MRGO region. Natural levees can be found at the land surface as in the case of Bayou Yscloskey and Bayou La Loutre, but because of subsidence, many levees can be found as much as 10 to 15 ft below the surface.

Swamp

Swamp deposits are somewhat rare in the MRGO landcut. Logs, stumps, and root systems intermingled with clay and organic material typify this deposit. They generally are found in a wide band flanking major distributaries. As with the adjacent natural levees, swamps are relatively surficial, although with subsidence they can be found below the surface as much as 15 ft. Swamp deposits have a low cohesive strength.

Marsh

Marsh vegetation blankets 90% of the study area. Its substrate is generally found from the surface down to a depth of 10 ft. These deposits, on the average, are 65% organic, and their cohesive strength is very low. In addition, water content ranges from 80 to 800% in dry weight. The upper 2 to 5 ft of a marsh deposit commonly is fibrous peat, an intermingling of modern root systems. The lower layers, down to the base of the deposit, is detrital peat, a granular composite of decomposed plant material. In short, marsh deposits are an extremely weak, highly saturated, and highly vulnerable, vast surface deposit.

Subsidence

Subsidence in the study area is an ever-present natural phenomenon caused by a variety of processes, including, the relative effect of sea level rise, basement sinking of deep strata, compaction of deltaic sediments through dewatering, and consolidation of nearsurface sediments from weight of natural levees (Kolb and van Lopik 1958; Adams et al. 1976). Kolb (1958) suggests that the single most important factor in the MRGO region affecting subsidence is the consolidation of high water content prodelta clays. Localized subsidence is evident in the Lena Lagoon area. Here the relatively dense Bayou La Loutre levees cause the adjacent marsh to sag. The evidence of this process is Lena Lagoon itself and numerous other adjacent small water bodies. Subsidence here is of such great magnitude that the process of organic litter accumulation cannot keep pace with land sinking, thus the water bodies have been formed.

In recent years numerous scientific investigations have attempted to quantify the subsidence process. Gagliano and van Beek (1970) have suggested a regional rate of 0.4 ft/century. Kolb and van Lopik (1958) suggest 0.8 ft/century (including sea level rise). Saucier (1963) determined an overall rate of 0.4 ft/century for the Pontchartrain Basin. Coastal Environments, Inc. (1972) found a range of 0.5 to 0.7 ft/century. Finally, in a recent study of National Geodetic Survey benchmark data, Watson (1982) determined a value of 1.3 ft/century. Clearly, these researchers have demonstrated that it is difficult to isolate a precise value for subsidence, but it is concluded that a value of 1 ft/century is a reasonable estimate.

Subsidence is a primary cause of marshland deterioration, as evidenced in the Lena Lagoon area. With no new sediment input from the Mississippi River system, subsidence allows marshland breakup and saltwater intrusion. But subsidence is not the only land loss culprit in the study area. As will be seen in future sections, the direct effect of saltwater intrusion from the MRGO and the impact of ships travelling through the MRGO have both generated impacts that greatly surpass the natural effect of subsidence.

Hydrology

Pre-MRGO Hydrology

Prior to MRGO construction, the study area was part of a natural hydrologic basin bound by Bayou La Loutre to the south and east, Bayou Bienvenue to the west, and Lake Borgne to the north. This basin was dominated by freshwater influence through rainfall. Precipitation (60 in per year on average) at that time would elevate general water levels in the marshes during each rain, and the resultant hydraulic head would cause flow toward Lake Borgne through an intricate maze of bayous and lakes. The migration of water was relatively slow; as a result, most of the environment was fairly fresh. Tidal influence did exist though, particularly near the Lake Borgne shore.

Rounsefell (1964) performed a 1960 salinity study along a transect which was to become the MRGO. An analysis of the salinity regimes demonstrate that in October 1960 (generally a dry month) salinity averaged 3.85 parts per thousand (ppt) (30 ppt represents pure sea water). A similar analysis for May 1960 (typically a wet month) demonstrates that salinity averaged 2.4 ppt. Both of these average salinity values show that this region was really quite fresh with very limited saltwater influence.

Post-MRGO Hydrology

In 1961 an MRGO access channel (18 ft deep and 140 ft wide) was completed between Breton Sound and the Intracoastal waterway (USACE 1961). This channel was later to be enlarged to full MRGO project dimensions; nevertheless, the year 1961 represents the first major hydrologic imbalance introduced to this basin in the MRGO construction history: the Bayou La Loutre Ridge had been breached. With this event, three major hydrologic modifications occurred: (1) saline waters from Breton Sound travelled with the tide, across the former natural levee barrier, into the fresh-to-brackish environment of the basin, (2) Breton Sound tides entered the basin, causing increased tidal amplitudes, and (3) precipitation that now fell into the basin no longer migrated slowly to Lake Borgne, they now were short-circuited by the channel.

The U. S. Department of Commerce (1983) recognized that "unpredictable tidal currents may be encountered [by ship captains] at places along the MRGO..." This observation is true to the extent that indeed tidal currents are an active force in the MRGO canal. But direct observation by the authors on April 14, 1984 suggests a refinement of this analysis. A very low water level (O ft NGVD) was observed at 0730 hours. The water rose steadily, and by 1500 hours the water level reached 1.5 NGVD; thus the water rose 0.2 ft/hour for a period of 7.5 hours. During this event currents were generally weak (approximately 1 ft/second) in the canal itself. But near the northeast shore where numerous bayous lead to Lake Borgne, currents reached velocities of 4 ft/second toward Lake Borgne. All major bayous were releasing MRGO waters rapidly into the Lake. These observations lead to an understanding of the hydrologic effect of the MRGO on the study area.

On a rising tide, the tidal wave travels up the MRGO relatively freely. The same wave, in contrast, flows with greater impedence as a result of bottom friction through the Mississippi Sound into Lake Borgne. Thus, a tidal lag occurs, a head develops between the MRGO and Lake Borgne, and water flows into Lake Borgne through such connections as Bayou Bienvenue, Bayou Dupree, Fort Bayou, Bayou Yscloskey, and Doulletts canal. The opposite is true on a falling tide. Water flows relatively freely out of the MRGO and a head develops from Lake Borgne into the canal. All major connections reverse flow, with similar water speeds occurring, given similar tidal amplitudes. These tidal conditions, essentially caused by the MRGO, provide a mechanism for saline waters to enter the wetlands of the study area.

The USACE (1981b) recognized high salinity levels in the MRGO and identified a gradient from 35 ppt at the channel entrance to 10 ppt at the Inner Harbor Navigation Canal (the landward terminus of the MRGO). Further, they suggested that no saltwater wedge exists (salinities are uniform from the water surface to the bottom of the canal). Wicker et al. (1982) provides a salinity data compilation that substantiates the USACE statements. Surface salinities in the study area during the period of November through April over the years 1968 through 1979 averaged 9 ppt. Surface salinities in the study area during the period of May through October over the years 1968 through 1979 averaged 12 ppt. And finally, maximum salinities during May through October, again for the same years, averaged 19 ppt.

The hydrologic situation provided by the MRGO is one of classic saltwater intrusion. Prior to the MRGO, salt levels were in the 2 to 4 ppt range. After MRGO construction, salt levels ranged from 10 to 20 ppt. The MRGO effect on water level and resultant tidal currents provides a mechanism for this salt to penetrate the wetlands of the study area.

Extreme Water Levels

Clearly, the MRGO is a waterway influenced by tides. This fact is important not only because understanding the tides provides insights into the causual relationship between tides and land loss, but also because it becomes imperative to understand tides in order to design a protective measure.

The U. S. Department of Commerce (1984) has determined through a 19-year water-level analysis of data derived from a tide gauge on Bayou Yscloskey at Shell Beach that the mean diurnal tide range is 1.3 ft. This value represents a compilation of all experienced high and low waters. Louisiana tides rarely conform to this generalization on a day-to-day basis, for they are significantly influenced by wind. When the wind blows, water levels respond quickly and dramatically, creating an influence that may far overshadow any underlying astronomical effect produced by the moon or the sun. A northerly wind blows the water out, and levels fall; a southerly wind blows the water in, and levels rise.

Figure 4 provides a 10-year summary of monthly lows and highs experienced at Shell Beach (USACE 1970-1979). Low waters are nearly always below marsh level (1.5 NGVD), and extreme lows fall 2 ft below marsh level (-0.5 ft NGVD). In short it is seen that extreme low waters have a relatively narrow range from marsh level to 2 ft below marsh level.

High water extremes are more variable than low water extremes. Figure 4 demonstrates that the typical monthly high is 1.5 ft above marsh level (3.0 ft NGVD). But occasionally there are spurious highs that may exceed this level. These highs are caused by extremely strong southerly winds, of which the highest are generated by hurricanes. In the ten-year period catalogued in Figure 4, three hurricane-related highs are shown: Hurricane Carmen, Hurricane Babe, and Hurricane Frederic. The highest level, that associated with Hurricane Carmen, caused a water level rise 3.5 ft above marsh level (5.06 NGVD). The years 1970 through 1979 do not provide the complete high water picture, for this epoch did not receive any truly intense hurricanes. Table 2 (USACE 1972) provides a broader time frame from which high

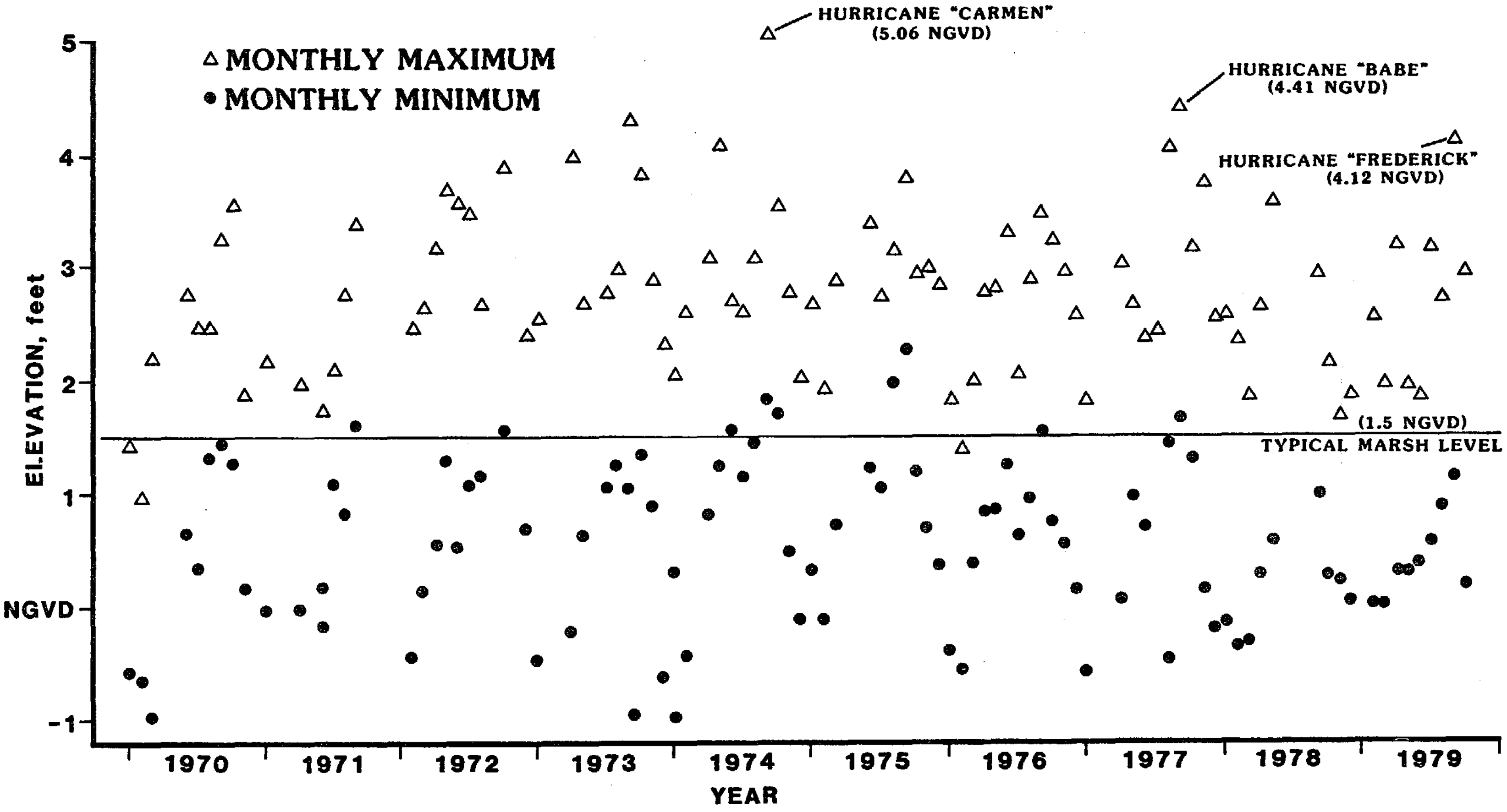

Figure 4. Monthly water level maximums and minimums from 1970 to 1979 for MRGO at Shell Beach, Louisiana. Data based on daily 8 a.m. stages (USACE 1970-1979).

Table 2. Extreme High Water Levels Experienced at Shell Beach, Louisiana (after USACE 1972).

Rank	Year	Surge (Feet above NGVD)	% probability*	Recurrence Interval (years)
1	1901	12.0	0.758	132
2	1947	11.2	2.27	44
3	1956	10.9	3.77	27
4	1965	9.3	5.30	19
5	1915	8.3	6.85	15
6	1915	6.0	8.33	12
7	1920	5.5	9.85	10
8	1909	5.0	11.36	9
9	1948	4.5	12.88	8

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* Probability = P

$$P = \frac{100\,(m - 0.5)}{y}$$

m = number of event (rank)
y = number of years of record (66)

water-level extremes can be viewed. Nine great hurricanes hit Shell Beach between 1901 and 1965. The greatest, that of 1901, provided a storm surge that rose 10.5 ft above the marsh (12.0 NGVD). Statistics show that this great level can recur an average of every 132 years. Smaller hurricanes, or hurricanes with a more distant landfall location, provide reduced storm surge heights, but they arrive more frequently.

Vegetation

A number of dynamic, constantly changing factors are involved in the initial creation of a marsh, its growth into steady equilibrium, and its senescent decline. Coastal marshlands are complex ecosystems composed of many related organisms and physical processes undergoing various stages of development or destruction. It is the amount of energy and matter coming into a marsh weighed against the amount of energy and matter exported from the marsh that determines its stage of evolution. A marsh remains in a state of equilibrium when gains equal losses. If a surplus of energy and matter exists, the marsh grows or becomes more productive. Under energy and matter deficits, marsh productivity and standing biomass decline, and vegetative areas revert to open water. Unfortunately, most Louisiana coastal marshlands are in a senescent stage, disappearing at an alarming rate. Marshlands in St. Bernard Parish, particularly in the study area, have deteriorated especially rapidly.

Natural marsh loss occurs from several factors, including subsidence, surface erosion, sea level rise, and compaction of sediments and organic detritus. All of these factors have undoubtedly contributed to land loss problems in the study area, but man-induced actions can be blamed for most of the problems. Canal dredging, levee construction, spoil deposition, and the elimination of the annual freshwater and sediment input from the Mississippi River have accelerated land loss rates.

Even though much direct land loss in the marshes near the MRGO can be attributed to active physical processes, the passive process of salinity intrusion has indirectly helped to destroy acres of marshland and has increased rates of erosion within the entire study area. The negative effects of salinity intrusion into fresh, intermediate, and brackish marshes have been extensively researched, publicly discussed, and scientifically presented, yet the process continues. In coastal marshes, a limited amount of saltwater intrusion naturally occurs during storms and tides, but the present magnitude of saltwater intrusion into interior marshes as a result of human activities is unprecedented. And perhaps no other navigation project in coastal Louisiana has resulted in such drastic, ecologically devastating saltwater intrusion as the MRGO has produced.

The effects of saltwater intrusion are most noticeable in the changes exhibited by marsh vegetation. Naturally occurring salinity increases result in a gradual, predictable sequence of plant succession toward a community of marsh grasses that is more tolerant of higher salinity. Plant communities that are less salt-tolerant are eventually replaced by more salt-tolerant communities.

At least three constant components interact in an established marshland environment: water, soil, and vegetation. (Other components such as wildlife and wind may interact periodically, but cannot be considered constant.) For hundreds of years these three components have interacted, producing freshwater swamps, and fresh, intermediate, and slightly brackish marshes throughout St. Bernard Parish. Bayou La Loutre acted as a natural barrier to saltwater intrusion into the study area, and no saline marshes were formed prior to MRGO construction. In fact, Lake Borgne provided the only brackish water source in the area, and strongly brackish marshes were very restricted in distribution (Wicker et al. 1982). In 1961, however, the MRGO was opened, the protective Bayou La Loutre was ridge breached, and saltwater poured into the fresh marshes of the study area. Two of the three major physical components of the marshland, vegetation and soils, were abruptly afflicted. The orderly evolution of physical, chemical, and biological systems within the marshland was suddenly terminated.

Most of the changes in vegetational species diversity and composition were evident just four years after the MRGO was opened (Wicker et al. 1982). Under more normal conditions of salinity increase, vegetational communities gradually change during decades, not just a few years. In the interim period following MRGO construction, freshwater plant communities died and before salt-tolerant plant communities became established, much of the vegetative cover deteriorated. Both aboveground and underground parts of freshwater plants died, leaving the marsh surface largely unvegetated and the subsurface soils devoid of erosion-resistant root systems. Marsh soils are generally perpetuated by the constant addition of organic litter generated from dead plant stems and leaves, and are held in place by plant roots. Compared to freshwater species, saline grasses produce less organic litter and less dense root systems.

The response of freshwater swamp and marsh soils to highly saline waters also accelerated land loss rates. As a result of the physical processes by which they were formed, swamp soils consist of alternating, intermingling layers of peat and clay. Marsh soils generally have the same composition as swamp soils, but their structure is different in that layers of peat almost always lie on top of subsurface clay layers. When either type of soil is flooded, the layers separate, with the organic peat layers becoming semi-fluid and easily removed by physical erosion. Also, saline waters bring in different anions and cations not normally abundant in freshwater. The ionic character of saline waters initiates new chemical reactions, increasing the anaerobic decomposition rate of the subsurface organic peats. As the peats decompose, their organic matter is readily dissolved by water, cohesive strength of the soil is further reduced, and soil particles are easily removed by erosive forces. Therefore, a salinity increase in areas of thick organic layers may result in the marsh breaking up and reverting into open water before saline grasses can vegetate the unprotected soils.

The degree to which the study area has undergone vegetational change since MRGO construction is graphically demonstrated in Figures 5a and 5b and Table 3. During the period of 1955 to 1978 the entirety of fresh and intermediate marshes, all cypress swamp, and 82% of the natural levee environment were converted to more saline environments or to open water conditions. The remaining 18% of the natural levee environment escaped conversions only by virtue of its higher elevation, where saline waters could not penetrate. The original 20,163 ac of brackish marsh, which existed in 1955, suffered 50% loss by 1978; only 9,533 ac remained. Saline marsh, of which there was none in 1955, increased to 5,052 ac by 1978. Open water (natural lakes and bayous) more than doubled in acreage during this same period. The effect of MRGO construction and its attendant saltwater intrusion has had a remarkably devastating impact on the natural vegetation of the study area.

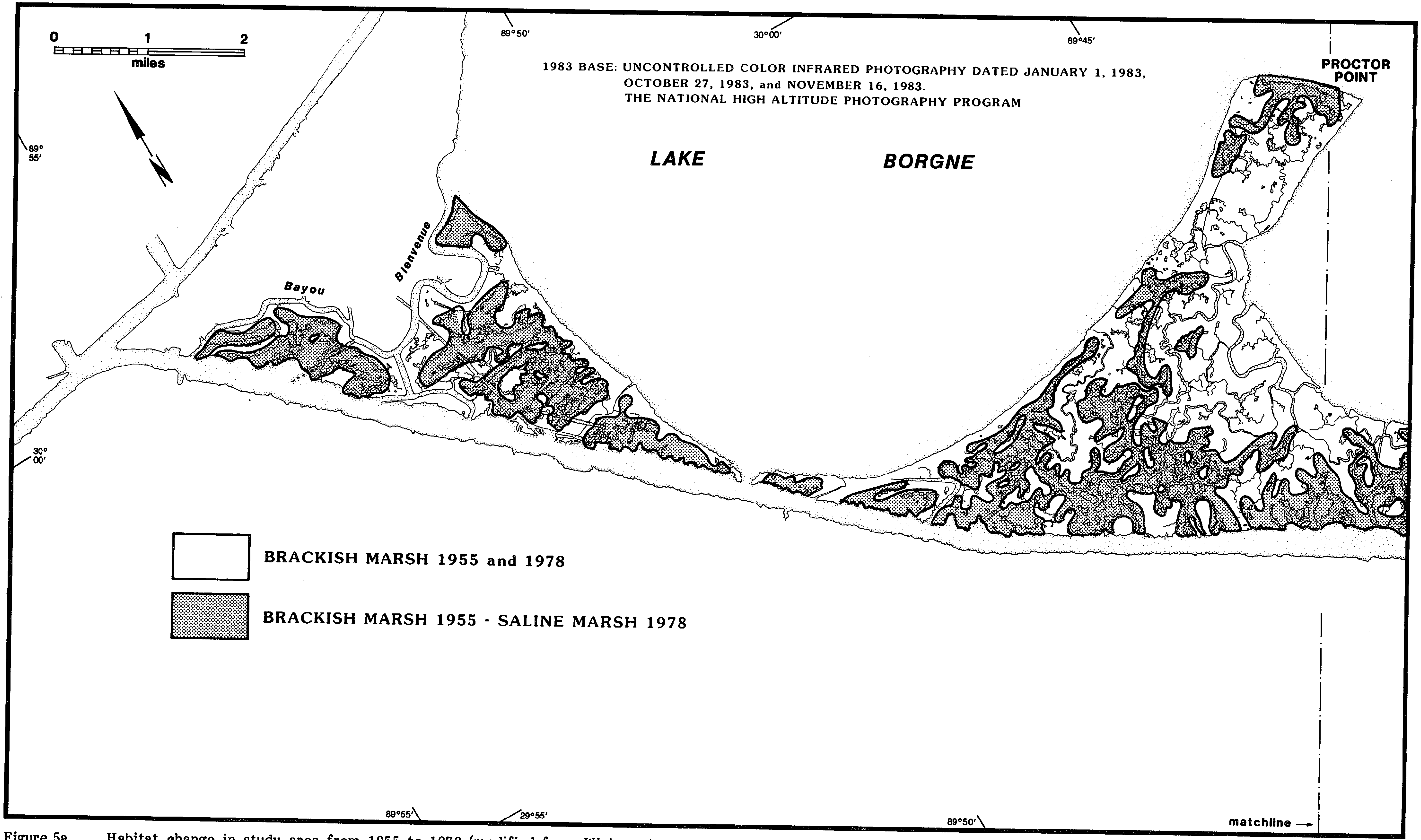

Figure 5a. Habitat change in study area from 1955 to 1978 (modified from Wicker et al. 1982).

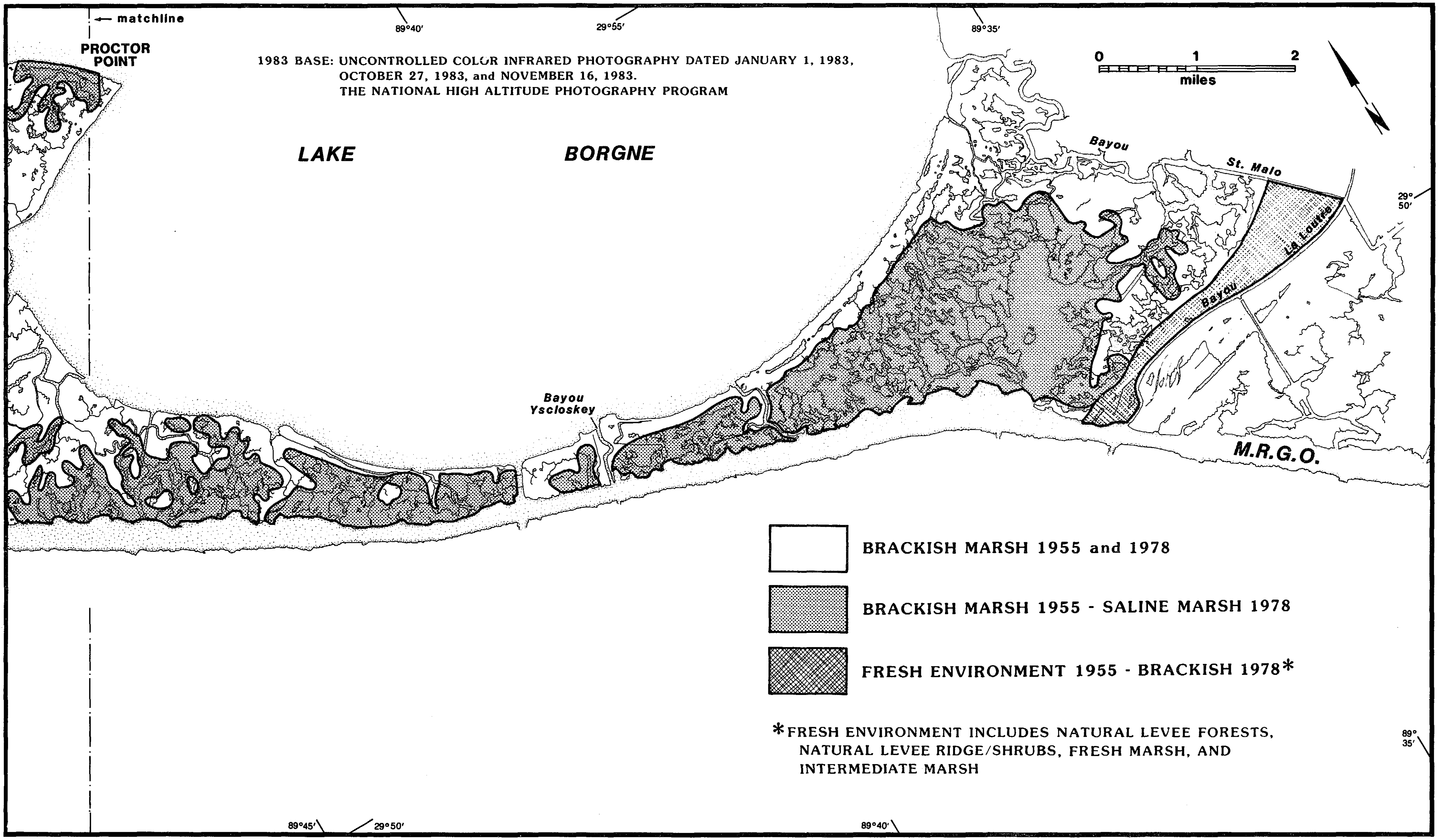

Figure 5b. Habitat change in study area from 1955 to 1978 (modified from Wicker et al. 1982)

Table 3. Habitat Types for Study Area in 1955 and 1978 (modified from Wicker et al. 1982).

Habitat Type	Habitat (acres) 1955	1978	Change (acres)
Fresh-to-Intermediate Marsh	74	0	-74
Intermediate Marsh	193	0	-193
Brackish Marsh	20,613	9,533	-11,080
Saline Marsh	0	5,052	+5,052
Spoil with Shrubs	8	39	+31
Natural Levee Forest	228	21	-207
Natural levee/ridge with shrubs	202	58	-144
Cypress Swamp	6	0	-6
Canals (petroleum and navigation)	43	96	+53
Open Water (Bayous, lakes, etc.)	2,530	6,107	+3,577
Development (houses and roads)	34	10	-24
MRGO (includes shoreline erosion)	0	3,015	+3,015
TOTAL	**23,931**	**23,931**	**0**

CHAPTER 3: MRGO HISTORY

Construction

The MRGO was authorized by the River and Harbor Act of March 29, 1956 (Public Law 455, 84th Congress, 2nd Session). Although there were numerous reasons for the authorization to build the MRGO, the most touted reason was to provide a shorter route for oceangoing vessels between the Gulf of Mexico and the Port of New Orleans (Coastal Environments, Inc. 1976). Once authorized, the USACE deliberated over possible routes for the canal and finally decided upon a route that would maximize the length of the canal through the wetlands of St. Bernard Parish. The Louisiana Wildlife and Fisheries Commission objected to the wetland route and suggested the construction of the canal through Lake Borgne in order to minimize ecological impacts associated with saltwater intrusion (Coastal Environments, Inc. 1976). The Corps did not heed the commission and finally chose the landcut route because it was determined that the Lake Borgne passage would create significant shoaling problems and thus increased maintenance dredging.

Work commenced in detailed planning of the MRGO in July 1956 (USACE 1961). The final design incorporated a 36-ft deep, 500-ft wide canal extending 76 mi to the 38-ft contour in the Gulf of Mexico (USACE 1981a). The landcut was maximized to extend 42.8 mi from the Inner Harbor Navigation Canal to Gardner Island. Canal walls were designed with 2:1 slope, and the right-of-way extended 750 ft from the center line into the marsh on the northeast side. A pair of 3-mi jetties at Gardner Island, comprised of 1,120,000 yd^3 of stone, was incorporated in the design to reduce shoaling in that reach. A turning basin and a lock with a connecting channel to the Mississippi River were also part of the plan (USACE 1981a). Total channel excavation was estimated to be 3 billion yd^3 with a total Federal cost of the project expected to be $1 billion (1961 dollars) (USACE 1961). All dredged material in the landcut was to be used to build a 4,000-ft wide, 10-ft high spoil bank on the southwest shore of the canal.

Actual construction began in March 1958 (USACE 1981a) with the first dredging contract awarded March 12, 1958 for excavation of a 2.5-mi section at the New Orleans Terminus (USACE 1961). The remaining MRGO channel was dredged in sections, each of which was dredged in three phases: (1) an "access channel" (18 ft x 140 ft), (2) an "interim channel" (36 ft x 250 ft), and (3) the final "project channel"

(36 ft x 500 ft). Some sections were completed to full project channel dimension before other sections had an access channel dredged.

The MRGO was constructed under 35 different contracts. The complete access channel was finished in March 1961 (USACE 1961). The complete interim channel was finished July 5, 1963, and was dedicated July 25, 1963, at which time the first commercial ship was allowed to travel from New Orleans to the Gulf of Mexico (Johnson 1966). The full project channel was completed in January 1968 (USACE 1981a).

In the study area (Bayou Bienvenue to Bayou La Loutre) full project dimensions were completed in October 1963 (Johnson 1966), but later the full project channel dimensions were exceeded when the hurricane protection levee project authorized channel deepening to allow for additional levee material. Between Bayou Bienvenue and Bayou Dupree, dredging in some locales reached -80 ft. Some shoaling has occurred since these dredging activities, but this portion of the MRGO to this day has depths that reach 70 ft.

Maintenance Dredging

Maintenance dredging was initiated in the MRGO July 1, 1965 (Johnson 1966) and has continued thereafter, but not on a regular basis. Shoaling is a continual process in the MRGO. Patrol Surveys are run periodically to detect impending critical shoaling; once it is identified, plans and specifications are prepared, advertised, and then awarded on a competitive basis (Hunt 1972).

Table 4 summarizes the annual average maintenance dredging from 1966 through 1983 in the three general sections of the MRGO: the landcut, the Breton Sound reach, and the Bar Channel. The high shoaling area (and accordingly, the high maintenance area) is the Breton Sound reach.

Here, 7 million yd^3 are removed annually. Given that this reach is 20.5 mi long, 341,000 yd^3 of shoal material are removed each year for each mile. This high rate of shoaling is a result of exposure to coastal currents and the subsequent drifting of Breton Sound bottom sediments.

Table 4. Maintenance Dredging in Whole MRGO from 1966 to 1983 (modified from Chatry 1984).

Section	Location	Distance (Miles)	Annual Volume (yd^3/yr)	Annual Volume Per Mile ($yd^3/yr/mi$)	Annual Cost Per Mile* ($/yr/mi)
Landcut	Inner Harbor Navigation Canal to Jetties	45.5	2,200,000	48,000	$24,000
Breton Sound	Jetties to Chandeleur Islands	20.5	7,000,000	341,000	$171,000
Bar Channel	Chandeleur Islands to MRGO Terminus	9.8	1,800,000	184,000	$92,000

*Based on 1983 estimate of $0.50/yd^3

In contrast, the landcut has an annual shoaling rate of 2,200,000 yd^3/year over a distance of 45.5 mi. Some of this reach has been overdredged in recent years in order to provide a sediment supply for the hurricane protection levee, which follows the MRGO from the inner harbor navigation canal (STA 0) to Verret (STA 1000). Thus, maintenance dredging in this reach has been less than what would have been normally required. Nonetheless, maintenance dredging data provided by the USACE demonstrate that for each mile of land cut, an average of 48,000 yd^3 must be removed on an average annual basis. In short, the landcut shoals only one-seventh as much as the Breton Sound Reach. Critical shoaling may have been higher if the portions of the landcut were not overdredged.

The study area (Bayou Bienvenue to Bayou La Loutre) all falls within the landcut section of the MRGO. Table 5 summarizes all maintenance dredging within this region. Between 1966 and 1983, 18,082,000 yd^3 shoaled and has been removed from the study area by a total of 10 separate maintenace dredging operations. The average annual maintenance dredge volume is, therefore, approximately 1 million yd^3. This translates into approximately an annual bottom buildup of 0.5 ft/year over the entire area. Assuming a 1983 cost of $0.50 per yd^3 (based on actual 1983 MRGO contracts provided by the USACE for MRGO work), the average annual maintenance cost in the study area is approximately $500,000.

Vessel Traffic

The first ship traffic on the MRGO was in 1960 (USACE 1960-1981), when it was under construction. Traffic from this time until 1963 was all associated with construction efforts. On July 25, 1963 the first commercial vessel, the S. S. Sud, traversed the MRGO from the Inner Harbor Navigation Canal to the open sea. From this time on, deep draft vessels representative of the world fleet traversed the MRGO at an increasing rate.

Figure 6 depicts the historical use of the MRGO in the form of short tons. From 1960 to 1978 cargo traversing the MRGO increased at a fairly uniform rate of .5 million tons per year. In 1978 cargo peaked at 9.4 million tons. By 1980 cargo fell off to a low level of 5.5 million tons, probably because of the world recession which occurred at that time. From 1980 to the present, cargo has again been on the increase. Future

Table 5. MRGO Maintenance Dredging in Study Area[1] from 1966 to 1983[2].

	ACTUAL DREDGING[3]			DREDGING IN STUDY AREA		
Date Completed	From (Sta)	To (Sta)	Volume (yd^3)	From (Sta)	To (Sta)	Estimated Volume (yd^3)
9/15/66	375	480	2,883,000	375	480	2,883,000
3/24/67	100	2160	3,276,000	375	1565	1,893,000
5/17/69	130	2250	5,840,000	375	1565	3,278,000
3/31/72	0	2180	6,005,000	375	1565	3,278,000
11/5/72	1280	2930	7,865,000	1280	1565	1,359,000
9/29/72	710	835	1,230,000	710	835	1,230,000
5/1/76	1546	1576	229,000	1546	1565	145,000
3/22/79	1250	1750	4,027,000	1250	1565	2,537,000
5/1/83	1480	1990	563,000	1480	1565	94,000
5/1/83	28	905	2,291,000	375	905	1,385,000

Study Area Maintenance Dredging Summary

No. of years (1966-1983) = 17

No. of dredgings = 10

Total Dredge Volume = 18,082,000 yd^3

Average dredge volume = 1,808,000 yd^3

Average Annual dredge volume = 1,064,000 yd^3/yr

[1] From Bayou Bienvenue (Sta 375) to Bayou La Loutre (Sta 1565).

[2] 1966 to 1972 dredging data from Lee 1972; 1976 to 1983 dredging data provided by USACE.

[3] Maintenance dredging operations occurring in the study area in part and in full.

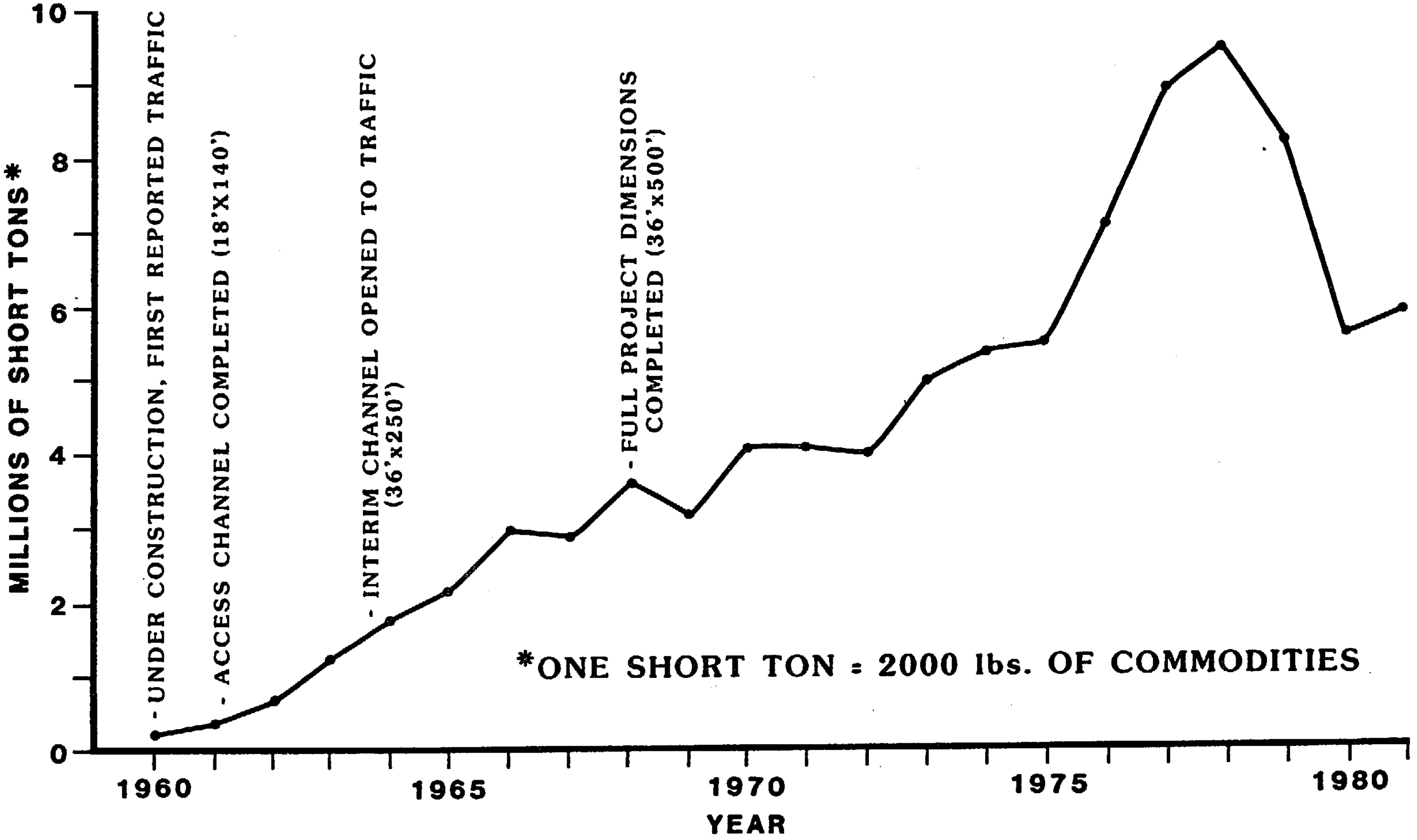

Figure 6. Commodity traffic history on the MRGO from 1960 through 1981 (USACE 1960-1981).

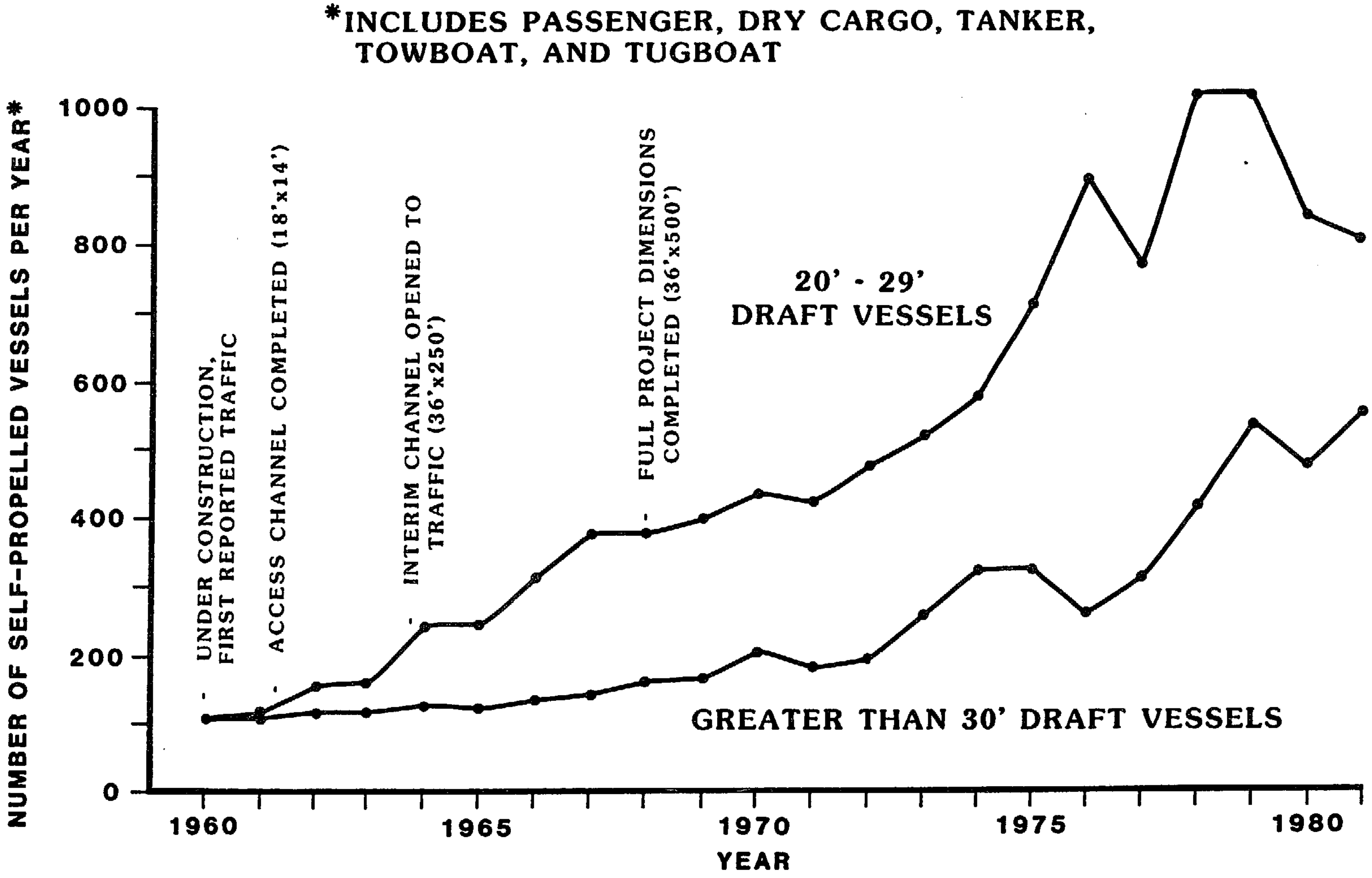

Figure 7. History of self-propelled traffic on the MRGO from 1960 through 1981 (USACE 1960-1981).

use of the MRGO is difficult to project, for cargo quantities are highly dependent on world economic conditions.

Figure 7 gives a historical breakdown of vessel traffic according to draft (distance from waterline to bottom of hull). The vessel draft class of 20 to 29 ft has steadily increased in volume from no vessels in 1960 to 920 vessels in 1979. World economic conditions in the early 1980s reduced traffic in this class thereafter. The greater-than-30-ft draft class (maximum draft is generally 36 ft, the authorized depth in the MRGO) had very low usage on the MRGO, from no vessels in 1960 to 80 vessels in 1972. Low usage during this period is due in part to full canal project dimensions (36 ft x 500 ft) not being complete until 1968. Usage steadily increased after 1978 in this vessel class to 440 traverses in 1981.

Estimated present day usage of oceangoing vessels on the MRGO can be derived from data provided by Figures 6 and 7. Twenty to 29-ft draft vessels approximate 800 vessels in 1984, or 2.2 traverses per day. The greater-than-30-ft draft class is estimated at 600 vessels in 1984, or 1.6 traverses per day.

CHAPTER 4: LAND LOSS ALONG THE MRGO SHORELINE

Ships and Ship Waves

Ship Wave Research

The first published analysis of ship waves was presented by William Froude (1877) during an investigation of the wave-making resistance of ships. Froude described the ship wave pattern as consisting of two parts. First, there is a set of diverging waves which are formed by the ship bow and radiate out from the ship. Second, there is a system of transverse waves formed at the bow with crests normal to the sailing line of the ship. Kelvin (1887) developed a theory which describes these phenomenon by studying the movement of a pressure point across a deep, still, and inviscous fluid. He found that the transverse and diverging waves would intersect at points called "cusps" which formed at an angle of 19^{o} 28' with the ship direction (Figure 8).

A parameter that has particular importance in describing waves produced by moving vessels is a dimensionless quantity known as the Froude number. The value of this quantity is defined by $F=V/(gd)^{1/2}$

where **F** is the Froude number;
V is the velocity;
g is the acceleration of gravity;
and **d** is the depth of the water.

In deep water the Froude number will approach zero and the wave pattern will essentially be that predicted by Kelvin. In navigation channels such as the MRGO, shallow water conditions exist. According to wave theory, the speed of a wave in shallow water is equal to $(gd)^{1/2}$, which is the value of the denominator in the Froude number. Havelock (1908) expanded on the work of Kelvin by studying the ship wave patterns in shallow water. The most notable of his findings was as the Froude number approached a value of 1, the wave pattern changed and the transverse waves became more prominent. When the Froude number was equal to 1, the wave pattern was composed solely of transverse waves. The condition at which the Froude number equals 1 is known as the "critical speed." At the critical speed, the ship is traveling at

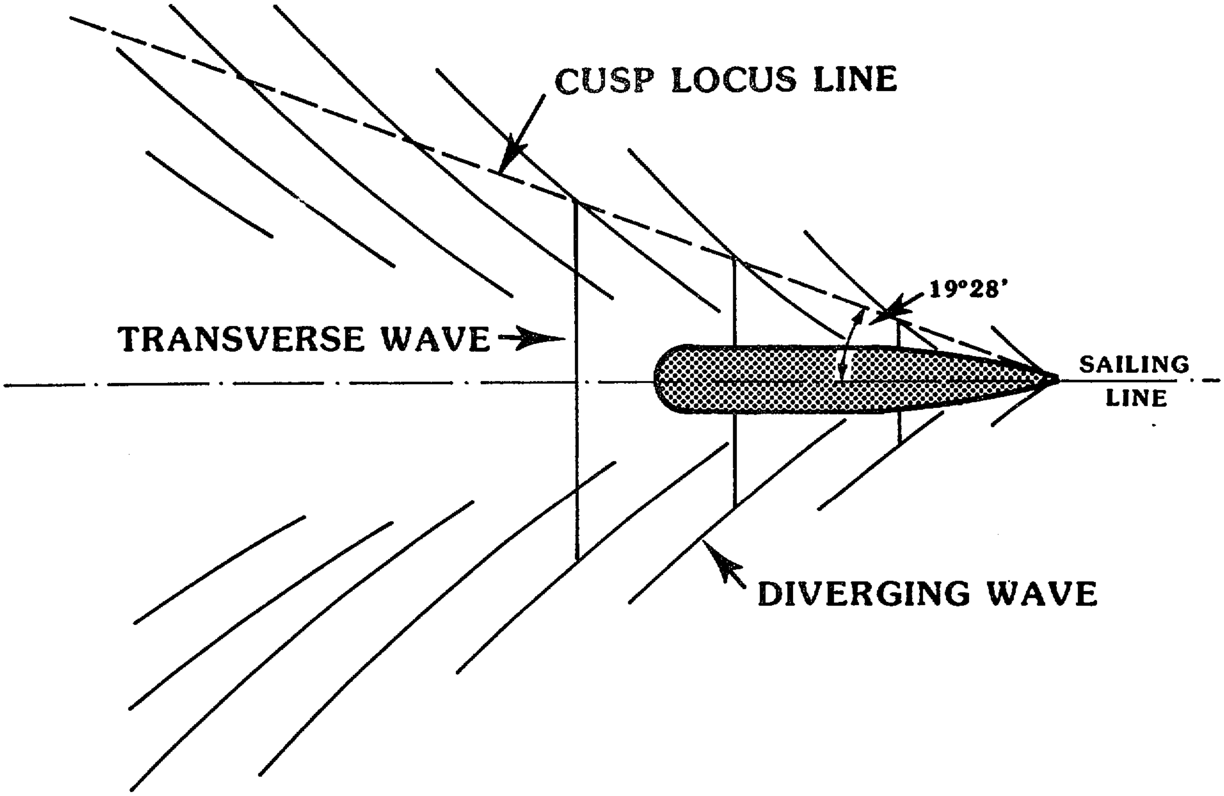

Figure 8. Deep water wave pattern generated by a moving ship (after Sorenson 1969).

the same speed as the shallow water wave and the two are "in phase." Because of this effect, ship speed and channel depth have direct effects on wave production.

Several investigations of ship waves using model ships to observe wave patterns have been made in recent years. Johnson (1958) used model ships in his experiments and was able to make some notable discoveries that reinforce basic ship wave theory. First, Johnson studied the angle which the wave cusp line made with the sailing line. He found that for low speeds (low Froude numbers) the angle was near the 19^{o} 28' which Kelvin predicted for deep water. As the speed was increased and approached F=1.0, the angle approached 90^{o}, which was predicted by Havelock (Figure 9). Johnson also investigated wave heights relative to ship speed. The wave height (designated as H max) is the height from trough to crest of the transverse waves. The test results produced a plot shown in Figure 10. These two plots indicate the same pattern of increasing wave height to F=1 and then a decreasing wave height thereafter.

Sorenson (1969) conducted tests on actual ships by having a wave-gauge mounted in a channel. He found that wave heights increase with ship speed; however, the effect was not as great as predicted by Johnson.

Hay (1968) performed wave height tests on model ships to determine the effects of hull configuration and distance from the ship. He found that for a particular ship moving at constant velocity the wave height increased with decreasing channel depth. This finding reinforces Johnson's because the Froude number increases in shallower water, provided the velocity is constant. Hay also found that as a general rule the wave height decreased with distance from the sailing line as Johnson had predicted earlier.

The most significant findings of Hay involved the effects of hull configuration on ship waves. He used a term called "fineness ratio" in evaluating hull design. Brebner defined fineness ratio as L*/ A where L* is the length of the curved portion of the bow at the waterline and A is the cross-sectional area of the parallel mid-body below the waterline (Brebner et al. 1966). The results of Hay's analysis showed that wave heights decreased with increasing fineness. It is of interest to note that the "A" term in the fineness ratio is calculated from the beam (width) and draft of a ship. These two terms are used more commonly in the description of ship size and in computing

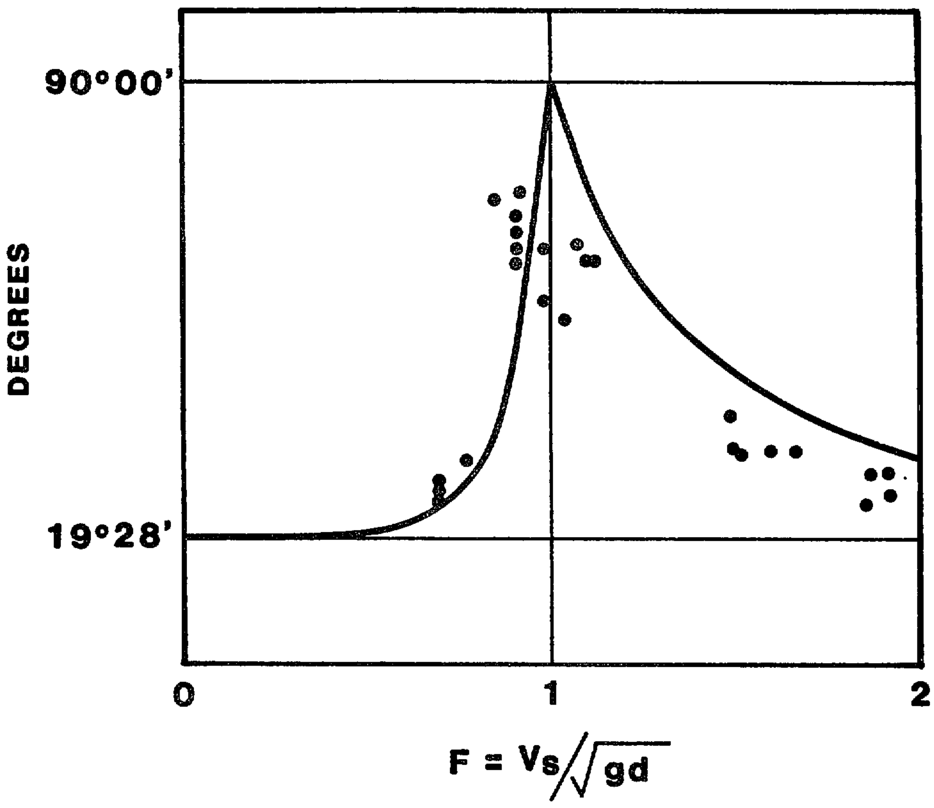

Figure 9. Cusp locus line angle from sailing line as a function of Froude Number (F) for a model ship (after Johnson 1958).

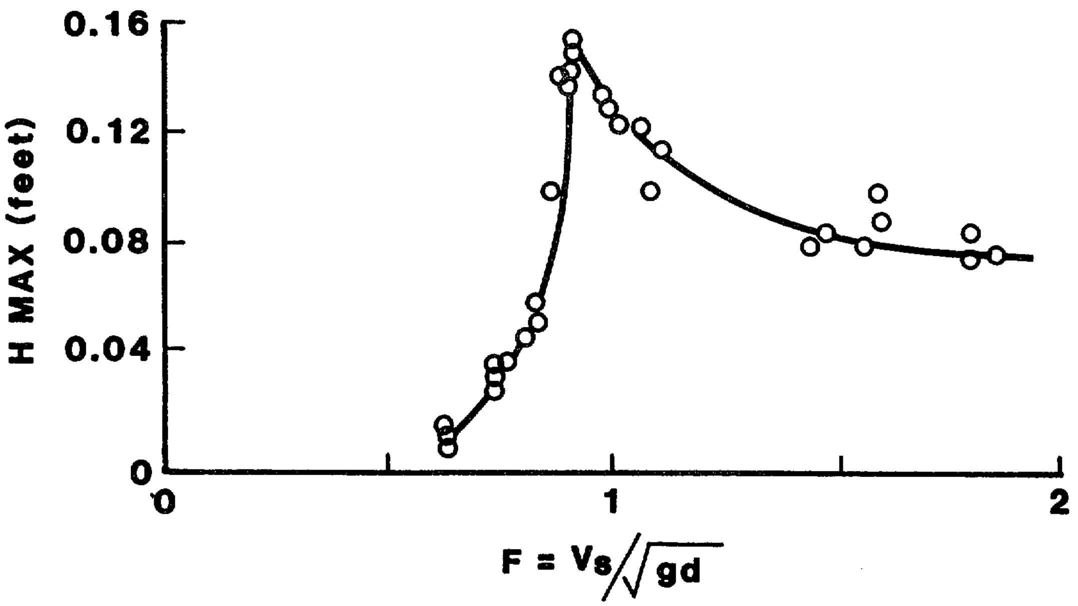

Figure 10. Maximum wave height as a function of Froude Number (F) for typical model (Johnson 1958).

the displacement. The fineness ratio is actually a measurement of the slimness of a ship; the slimmer ships have larger fineness ratios and cause smaller transverse waves.

Johnson (1968) performed another set of tests to measure wave heights in shoaling waters (areas where the channel side slopes are very low angle). For this analysis, Johnson used model ships and placed wave gages in the channel and in the shoaling area, both equidistant from the sailing line. The slopes used were 1:5 and 1:10 and also a composite slope with a 1:5 becoming a 1:10 at the shoreline. The results generally showed that the wave heights were smaller on the slope than in the channel, particularly with the 1:10 slope. In summary, there apparently are two effects which cause the waves to degenerate: an increase in distance from the sailing line, and movement over flat slopes in shallow water.

Ship Movement in Restricted Waterways

The movement of a ship in a restricted waterway—one with banks or jetties—is totally different from ship movement in open water. Not only is a restricted waterway shallow, but it also has a finite amount of water present within its cross section. As a large ship moves in a restricted waterway, water is continuously being displaced and replenished. Because the water supply is limited, the processes associated with this phenomenon are very dynamic and affect both the ship movement and the waterway shoreline.

The transverse waves are the result of the displacement effects of a moving vessel. When a large ship moves in a restricted waterway it pushes a wave ahead of it. Differential pressures result along the side of the ship creating an increased water level at the bow and stern and a decreased level along midship. A water surface profile along a model ship is shown in Figure 11. This phenomenon has been described as a trough extending from ship to shore and moving at the same speed as the ship (USACE 1983a). The USACE study also stated that as speed was increased the trough deepened. The depressed water level along midship represents a suction pressure which draws water in to fill the void left by the ship's displacement. As this wave passes along the shoreline the water level is initially raised and then lowered as the suction force draws water from the banks. As the ship passes, the water again begins to return to the shore and the water level eventually equilibrates as the wave dampens out.

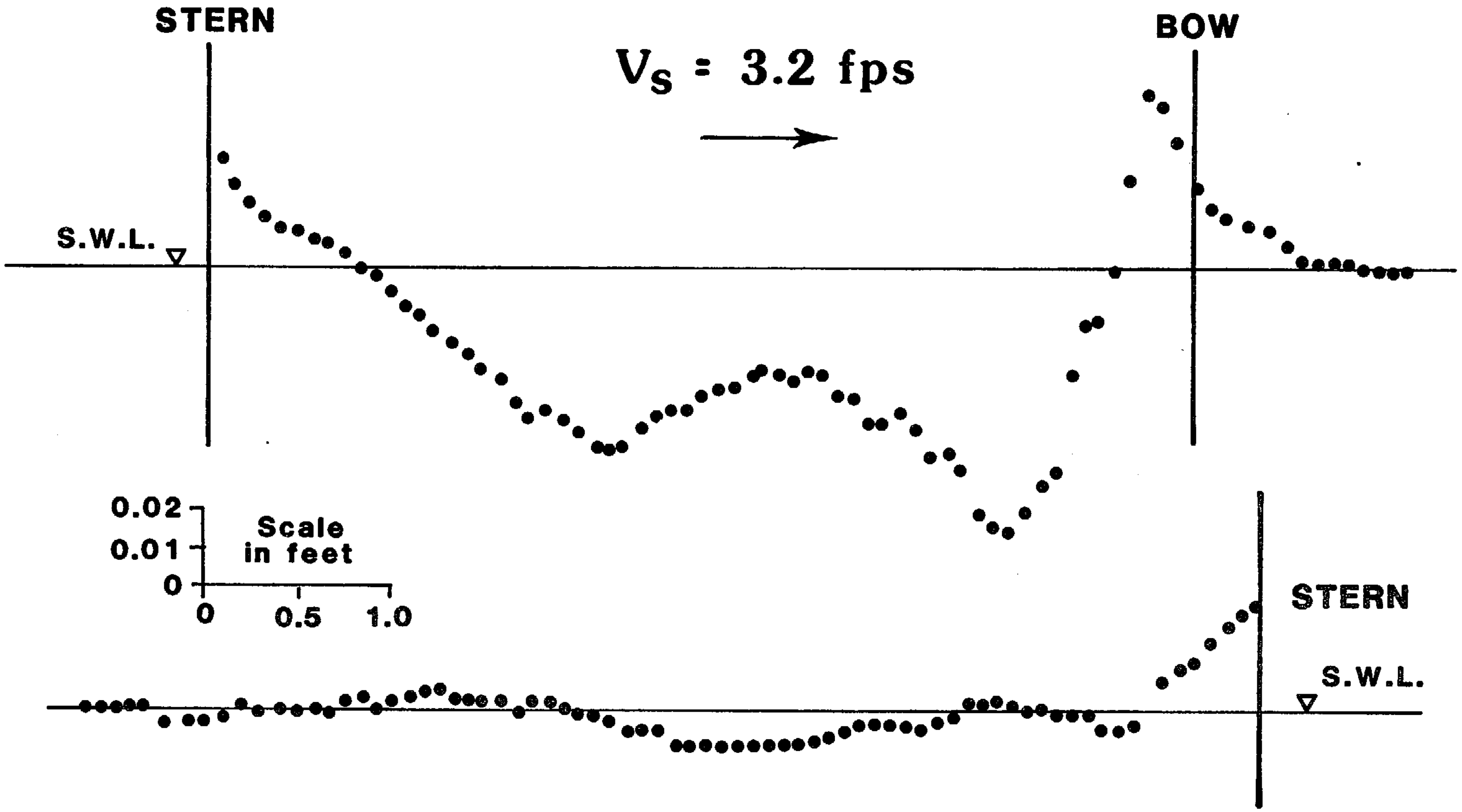

Figure 11. Water surface profile along sailing line and ship hull for a model run in a restricted waterway.

The violence of this water displacement reaction is dependent upon the speed and draft of the ship (U.S. Department of Commerce 1983). As speed increases, the displacement fill rate increases. Likewise, the suction effect along the ship is greater for a larger displacement vessel. These two factors work together to increase the size of the transverse wave.

The size of the ship relative to the waterway also has effects on the vessel motion and wave production. A waterway which is "tight" or has little room for maneuvering allows for an increased displacement effect (Hoobler 1984). The effects of the water movement processes resulting from ship passage in restricted waterways cause the ship to settle lower into the water. This phenomenon is commonly known as "squat" (USACE 1981b). In narrow waterways the displacement effects are greater and the ship experiences increased squat because of the limited supply of water to refill what the ship displaces. Vessel squat is most important for large draft vessels where the propeller reaches near the bottom of the waterway. The propeller must draw water in order to operate. When it is near the bottom of a shallow channel, there is a limited supply of water available; consequently, the displacement effect becomes more exaggerated and the transverse wave is enlarged.

MRGO Traffic Analysis

The MRGO is utilized by a wide variety of oceangoing and shallow draft vessels (for a historical review of vessel traffic, see Chapter 3). The shallow draft vessels include large tows, commercial fishing boats, oil field boats, offshore drilling craft and pleasure craft. The deep draft vessels include dry bulk carriers, tankers, general cargo vessels, and container ships (USACE 1981b). A sample of the MRGO traffic from January to March of 1984 was analyzed using the Vessel Traffic Service data provided by the U. S. Coast Guard. This information includes the date and time of specific ship passages along the MRGO, their average speeds, and their physical dimensions (beam, length, and draft).

The average speed for selected ships is plotted as a function of beam (width) in Figure 12. Most of the speeds fall within the 12- to 17-mph range. It is of interest to note that the "critical speed" (as determined by equations provided by Havelock, 1908) on the MRGO with a 36-ft depth is 23.2 mph. The critical speed is defined as the speed at which the Froude number equals 1 and, therefore, the wave height maximizes.

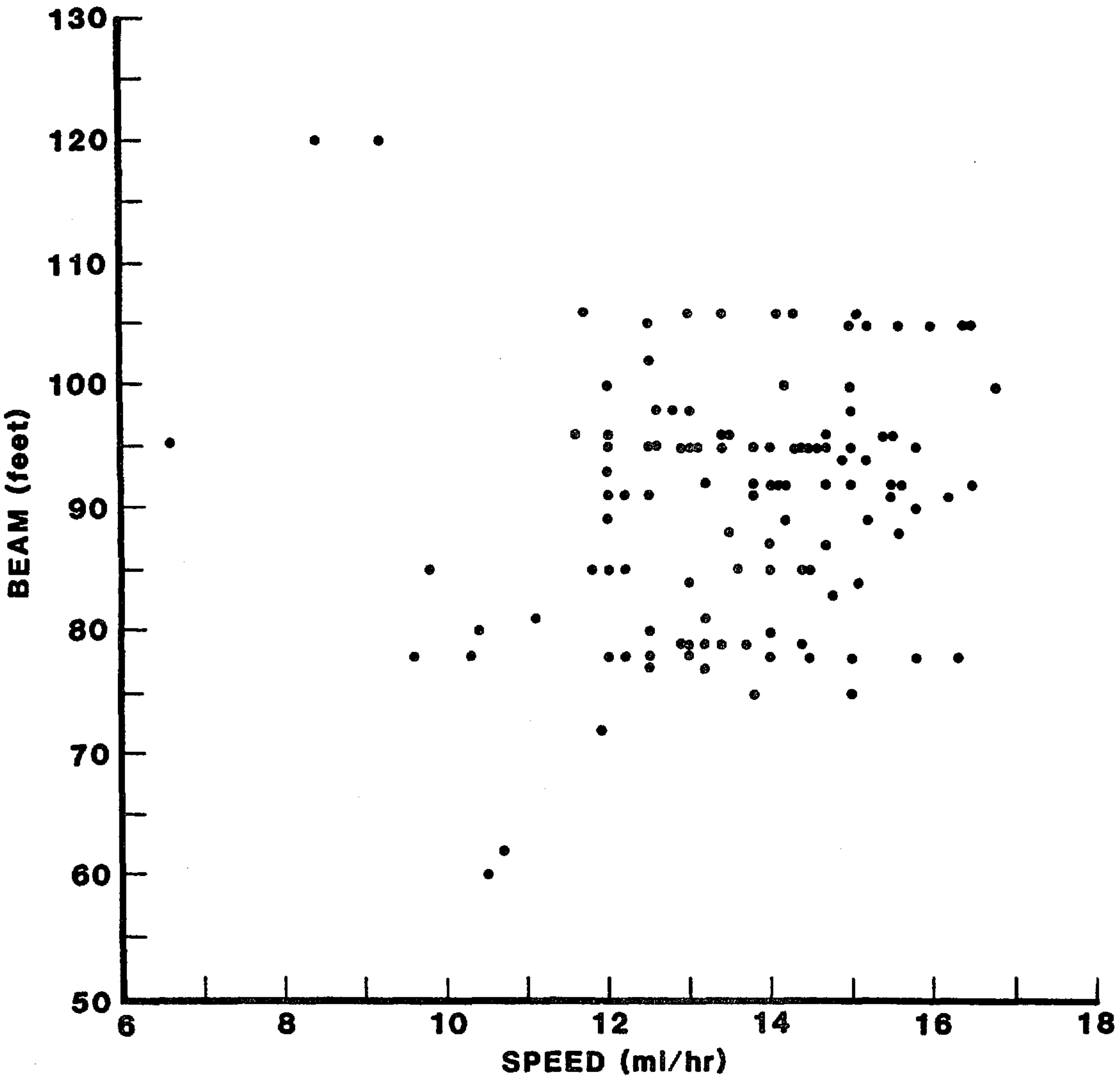

Figure 12. Relationship between ship speed and ship beam for "regulated" vessels on the MRGO between 1 January 1984 and 31 March 1984 (data provided by Vessel Traffic Service, U.S. Coast Guard).

Both Johnson and Sorenson predicted that at a value equal to 0.6 of the critical speed, the wave height begins to increase rapidly. On the MRGO this value represents a speed of 13.9 mph, which lies within the typical range of speeds. Speeds in excess of 13.9 mph would be expected to cause greatly increased waves.

The length and draft of selected ships on the MRGO has been plotted as a function of beam in Figures 13 and 14. Most of these ships have beams from 80 to 110 ft, drafts from 20 to 35 ft, and lengths from 550 to 750 ft. The majority of the ships selected are designated as "regulated" (a vessel of which exceeds dimensions outlined by the Vessel Traffic Service of the U. S. Coast Guard: greater than 600-ft length, greater-than-80-ft beam, or greater-than-30-ft draft). There are many "unregulated" ships that use the MRGO; however, these are smaller and less important in this analysis.

The USACE conducted a study on the Great Lakes connecting channels to determine the effects of increased vessel size (USACE 1983a). A calibrated computer model was used to draw relationships between drawdown and vessel speed (drawdown is the change from normal water level to the most depressed level). A set of curves was generated for various combinations of beam and draft (Figure 15). The larger beam and draft ships have larger displacements and thus create larger waves.

A similar type analysis was conducted by the authors using MRGO water level gage data from the USACE. When a ship passes in the MRGO, the change in water level is imprinted on the recording gage. The water level gages are protected from wave wash by a well; therefore, the readings are not as large as the actual change in water level surrounding the well. These gage movements were plotted against the average velocity from the Coast Guard data for two groups of ships, one group approximately 96-ft beam by 32-ft draft and the other 75-ft beam by 24-ft draft (Figure 16). Again, the same type of pattern is evident, with the group of larger ships producing greater waves. For this analysis it was necessary to use the sum of the largest and smallest ships to attain the expected relationship. Some of the medium-size ships actually caused movements as great as the larger ships. This may be explained by inaccuracies in using the average speeds or from problems in interpreting the data. A stronger possibility is that the hull configuration (fineness ratio) is having effects on wave size.

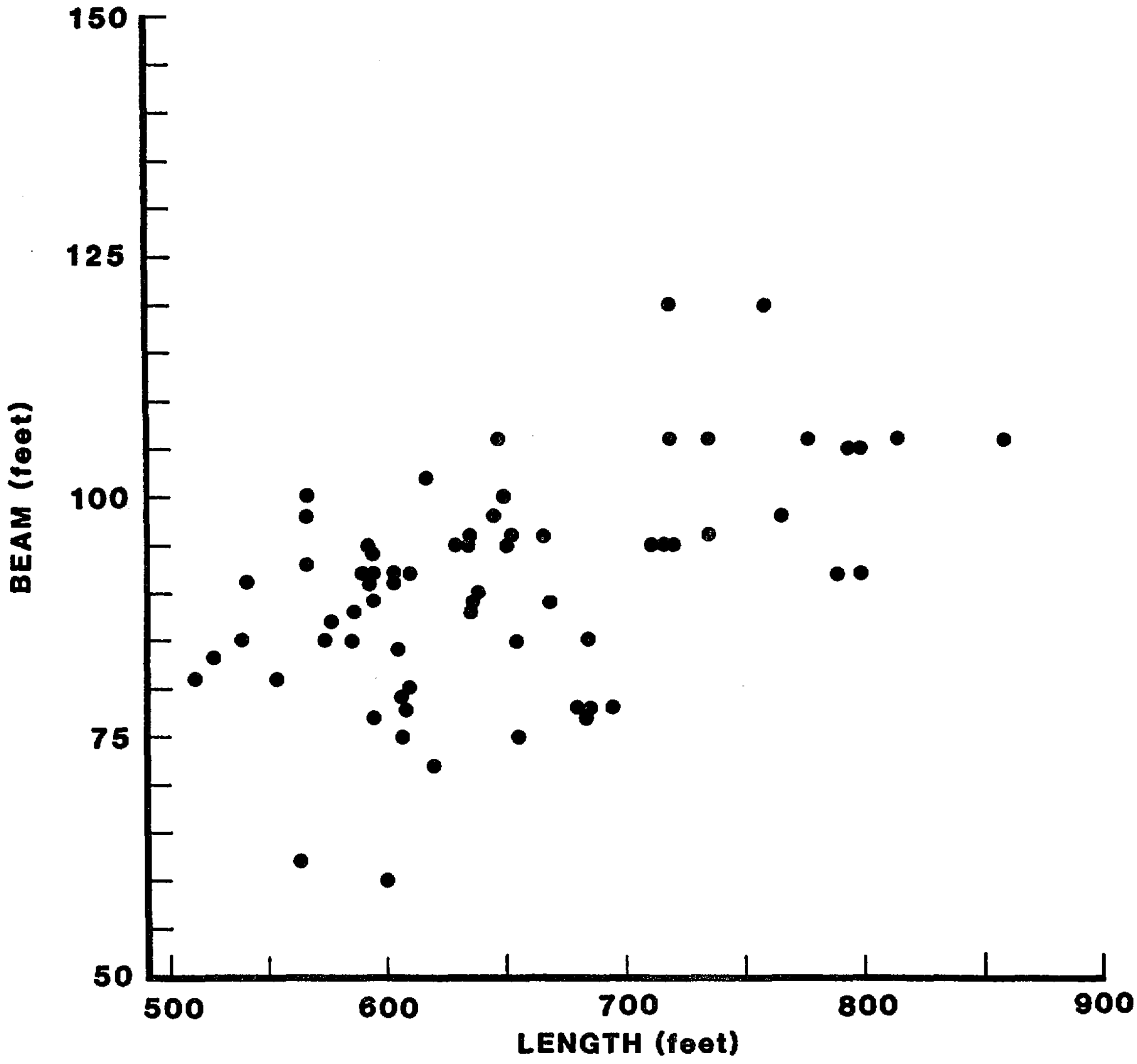

Figure 13. Relationship between ship length and ship beam for "regulated" vessels on the MRGO between 1 January 1984 and 31 March 1984 (data provided by Vessel Traffic Service, U.S. Coast Guard).

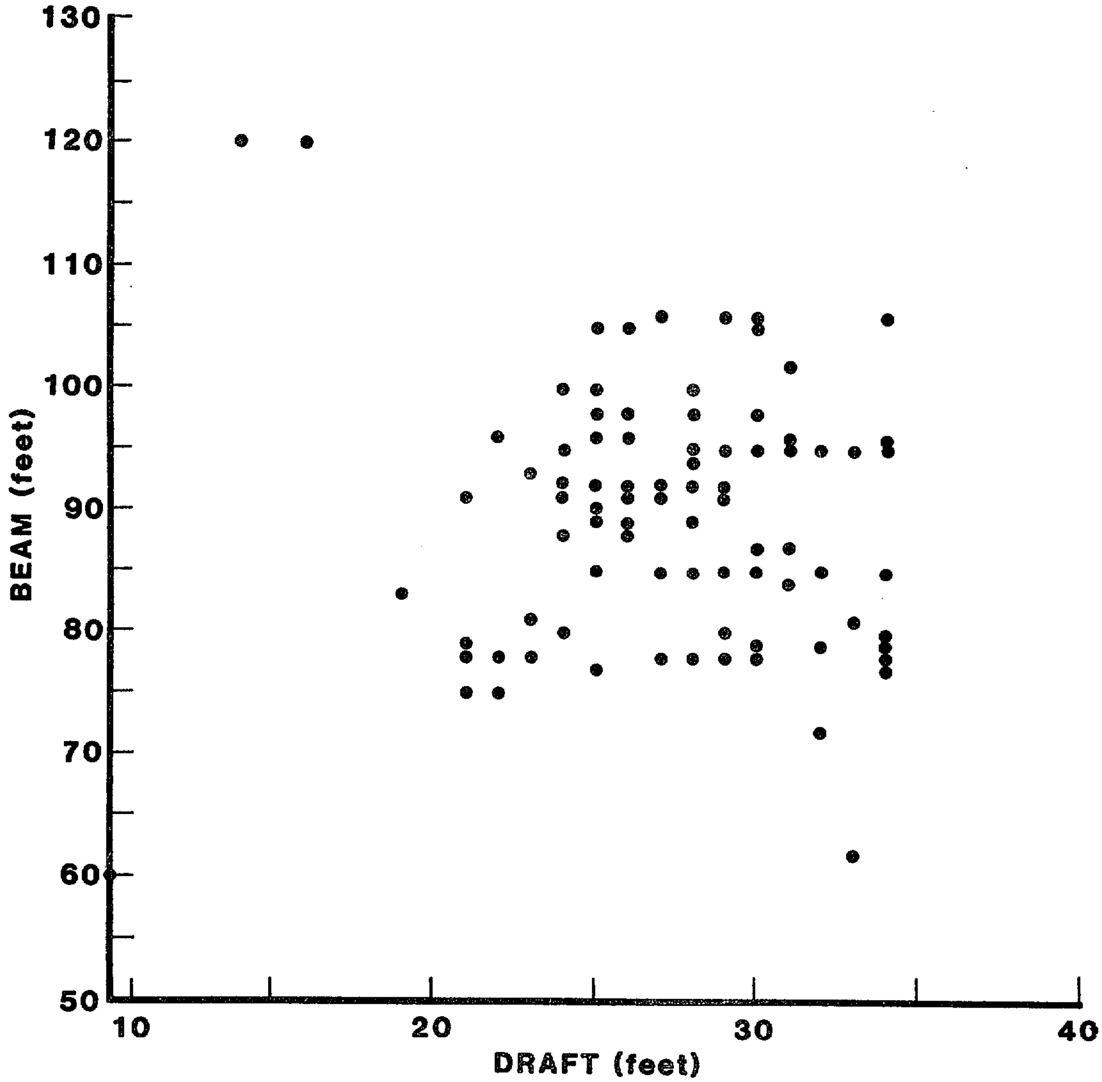

Figure 14. Relationship between draft and beam for "regulated" vessels on the MRGO between 1 January 1984 and 31 March 1984 (data provided by Vessel Traffic Service, U.S. Coast Guard).

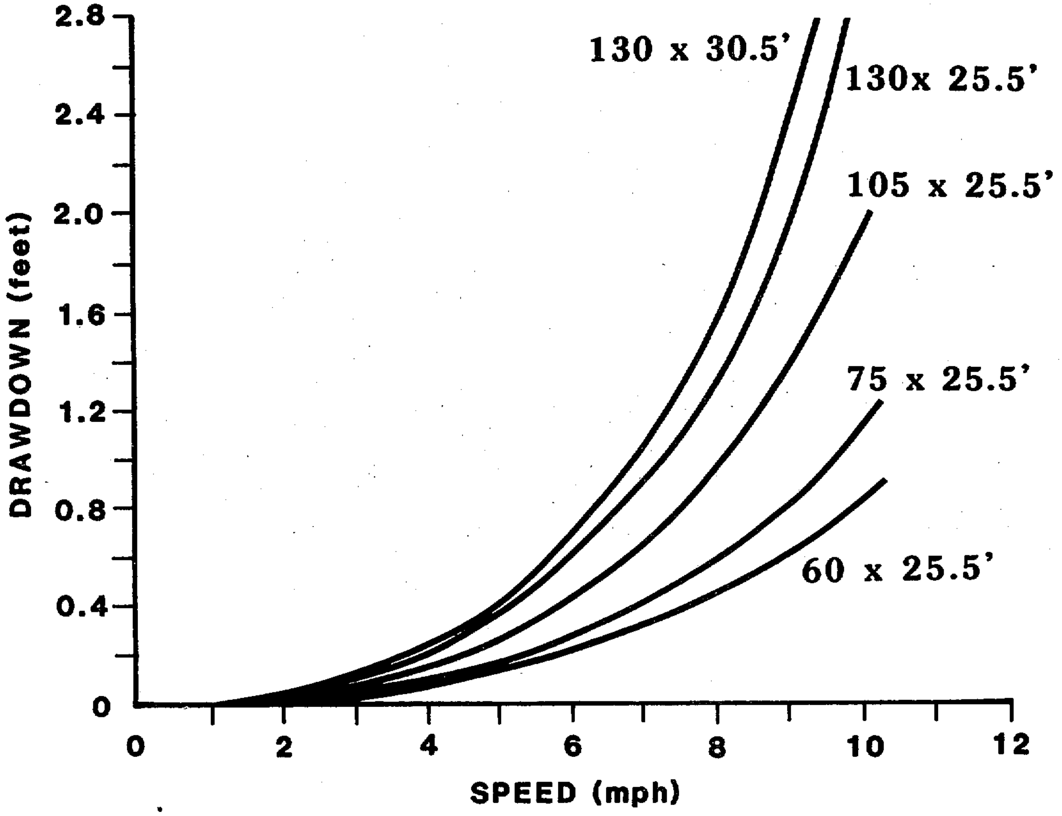

Figure 15. Model relationships between speed of vessel and resultant drawdown for various vessel classes (beam vs. draft) on the St. Mary's River (after USACE 1983a).

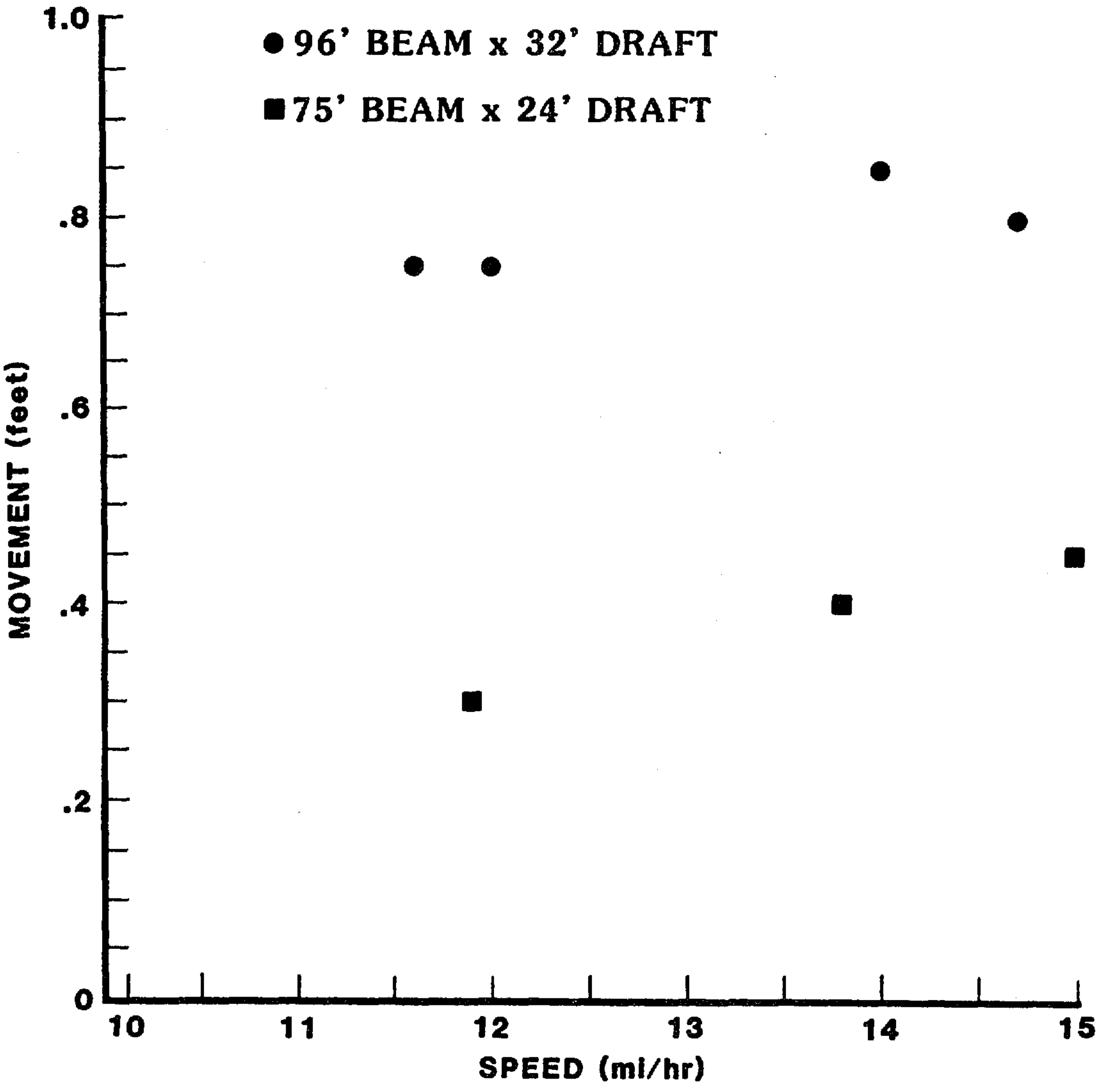

Figure 16. Relationship between ship speed and water-level movement on the MRGO for two contrasting vessel classes. Note that recorded movement is only a fraction of actual movement. (Vessel speed from data provided by Vessel Traffic Service, U.S. Coast Guard; water movements from USACE tide gauge data).

MRGO Traffic Observations

The authors made several trips to the MRGO to directly observe the passage of vessels. The objective was to observe the waves that occur on the MRGO shoreline as a ship approaches and travels past a location. Staff gages were used to measure the water level rise and fall. Time lapse photography was used to record the water level during the passage of several ships. The observations were all made from the northeast side of the MRGO at various locations. Several of the "regulated" vessels were observed including one of the largest ships to use the MRGO. A number of the smaller "nonregulated" ships also were encountered. As was expected, the water level changes resulting from the passage of these smaller ships were almost unnoticeable, with the only action being the result of the diverging waves hitting the shoreline. The waves of the "regulated" ships were found to follow what was described for a restricted waterway. Typically the process began with a small "surge," or rise of the water level, followed by a "drawdown," or water level decrease, and ending with the "return flow," causing another water level increase. The initial surge was not significant in any of the observations; the drawdown and return flow proved to cause the largest fluctuations in water level.

The largest ship observed, one of the largest displacement vessels using the MRGO, had a draft of 34-ft, a beam of 96 ft, and a length of 653 ft (Table 6). This ship was observed at station 1627 traveling up the MRGO at an estimated speed of 13.5 mph. The shoreline in this region is fairly uniform, and the distance to the centerline of the channel was 750 ft. The small surge flow could be seen along the shoreline where the ship was passing. The drawdown began as the ship's bow passed and depressed the water to 4 ft below the still water level (Figure 17). As the ship's stern passed, the return flow began to arrive in a very turbulent fashion, increasing the water level to 2 ft above the still water level. In accordance with this, almost 2 ft of water overflowed into the marsh. The water level then dropped, allowing flow out of the marsh in sheet-like fashion. The diverging waves began to hit the shoreline at approximately the same time as the return flow. The water level continued to fluctuate after the ship passage before returning to still water level in approximately 10 minutes. It was observed that the water was very turbid after ship passage, whereas it was clear green before. During the drawdown phase debris was seen being carried into the channel by the water flow from off of the banks. In general, an extreme amount of turbulence was observed to occur in the shallow water at the

Table 6. Observed Ship Passages on the MRGO.

Date	Vessel Name	Direction	Draft* (feet)	Length* (feet)	Beam* (feet)	Speed* (mi/hr)	Maximum Surge (feet)
3/28/84	Hera	Upbound	21	607	79	13.0	2.0
3/28/84	Columbus Queensland	Upbound	29	604	91	12.2	2.1
4/18/84	Panama	Upbound	24	685	78	15.0	2.4
4/18/84	Strider Juno	Downbound	24	416	65	15.0	1.0
5/14/84	Brussels	Upbound	34	653	96	13.5	5.7
5/14/84	Brussels	Upbound	34	653	96	13.5	2.4

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* Data provided by Vessel Traffic Service, U. S. Coast Guard

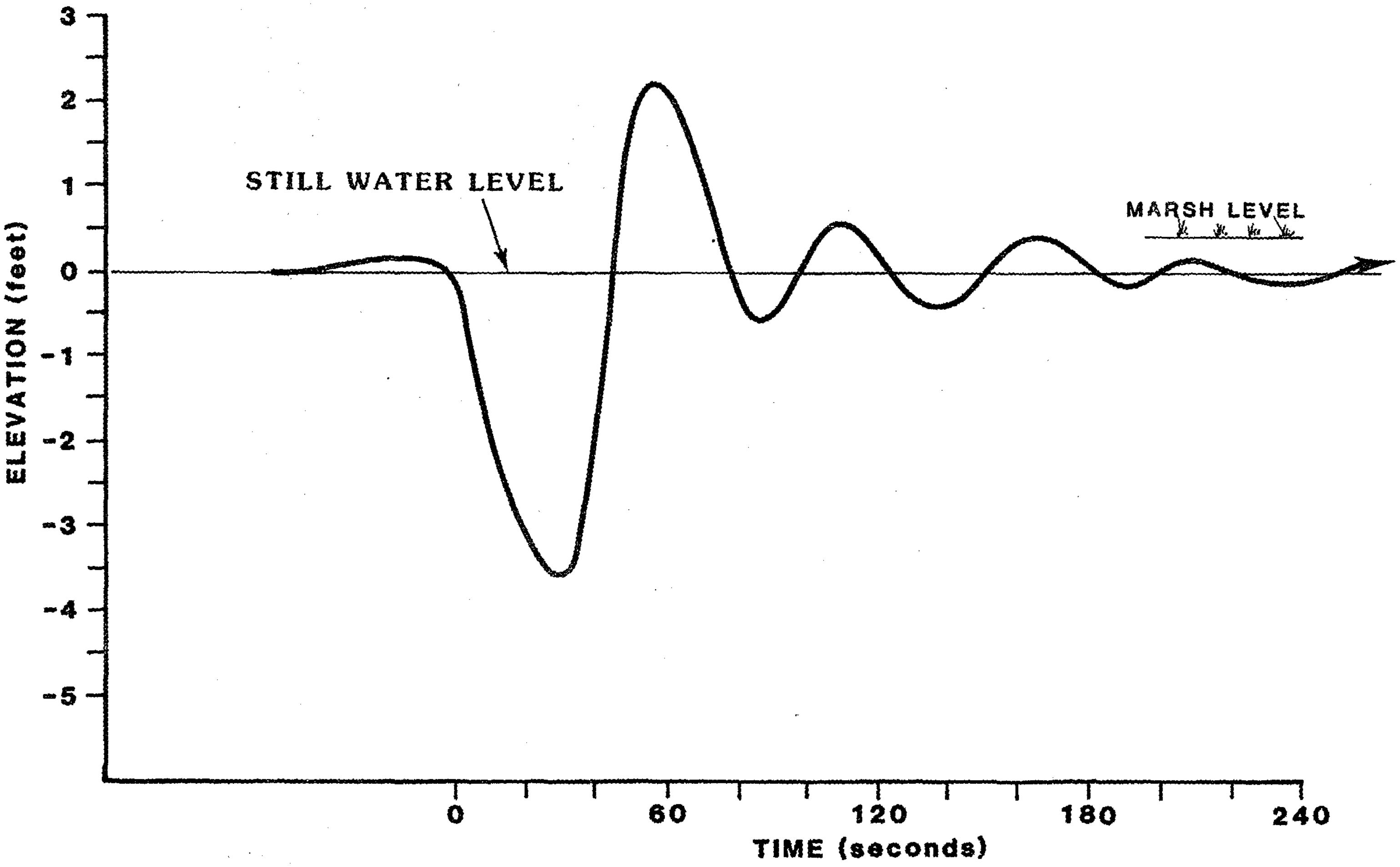


Figure 17. Water level response at MRGO station 1627 as the "Brussels" passes upbound.

shoreline during the drawdown and return flow phases. The turbidity of the water after ship passage is an indication of the erosive processes occurring.

Another observation was made on this same ship passage at station 1410. At this location the center of the channel was 800 ft away. The observation site was also adjacent to a major bayou and the drawdown and return flow combined to have a total wave movement of only 2.4 ft (Table 6). It was immediately apparent to the observers that the reduced wave activity was in part caused by the hydraulic influence which the bayou provided. The displacement effect in the restricted channel was modified by the reservoir of water in the interior marshes which is accessed to the MRGO by the connecting bayou. As the ship passed, and as the drawdown proceeded, Bayou flow provided a direct water source. In effect, the MRGO in this locale is less of a restricted waterway.

Another ship (the Hera), with a 21-ft draft, a 79-ft beam, and a length of 607 ft (Table 6), was observed at station 480, which is on an intact section of shoreline. The distance to the channel centerline was 550 ft, and the ship had an estimated speed of 13 mph. The wave patterns were the same with the drawdown and return flow each combining to create a wave of 2 ft. During the drawdown process it was observed that water was drawn from the marsh at certain locations to feed the drawdown. The velocities of the water leaving the marsh and moving over the exposed bank were well in excess of 5 ft/second, making this a very erosive process. Once again, a large amount of turbulence was noted in the shallow water during the drawdown and return flow. The diverging waves reached the shoreline after the return flow had occurred.

The two ships for which observations were presented here represent above-average and below-average sizes of regulated vessels on the MRGO. It is unlikely that many of the ships on the MRGO will cause a 6-ft wave (4-ft drawdown, 2-ft return flow). However, many ships will cause waves which are larger than 2 ft.

The diverging wave system has not yet been given serious consideration, because the drawdown and return flow elements of the transverse wave are much more erosive processes. Field observations indicate that a 1- to 2-ft diverging wave is the normal case. These waves do not reach the shoreline until after the transverse wave has passed; therefore, they attack the shoreline at normal water levels. In short, the diverging waves are of minor significance when compared to the overwhelming erosion force imposed by the transverse wave.

The Ship Wave Erosion Process

The dominant cause of erosion on the MRGO shore is ship waves produced by large displacement, oceangoing vessels. As one of these vessels passes, whether upbound or downbound, a series of wave events are produced, each of which has its own characteristic and erosion potential. Each significant phase of the erosion producing wave is described below.

The first wave event is the initial water level rise, which is almost imperceptible, for it is a slow rise associated with the bow wake that proceeds to a maximum height of only 0.25 ft above still water level over a period of approximately 30 seconds. There is little to no erosion produced by this event.

The second wave phase that encounters the shoreline is the drawdown. This event, which is generally radical and has much erosional capacity, proceeds over a period of approximately 20 to 30 seconds, dropping water levels 1 to 4 ft below still water level. Currents out of the marsh areas and off of the shallow bench adjacent to the shore can reach 5 to 6 ft/second. Debris (vegetation and soil) is carried toward the MRGO channel and an erosive force is often directly applied to the underlying marsh substrate at the marsh-water interface.

The third wave phase is met when low water is reached on the drawdown and the return flow moves back towards the shoreline. Currents reach 5 to 10 ft/second, allowing for erosive forces similar to those that exist during the drawdown. The return flow is the direct response to the drawdown; as such, it proceeds with vigor, raising water levels as high as 1 to 2 ft above still water level. If still water level were near marsh elevation, the return flow would thrust water into the marsh area, both through any bayous or cuts that exist and directly as sheet flow over the flat surface itself. Erosion of marsh and the shallow areas adjacent to the marsh can be severe.

The fourth phase of wave flow is the second drawdown, which occurs in harmonic response to the elevated water level associated with the return flow. This phase carries extreme erosion potential, for now waters on the marsh rush back to the MRGO channel, allowing for channelization and removal of debris from the marsh surface.

After the second return flow, numerous wave harmonics proceed for a period of up to 10 minutes until all wave energy has dissipated and still water level has resumed. Erosive forces during this water relaxation period are secondary in nature when compared to previous wave episodes.

Field observations of the transverse wave phenomenon and the resultant erosion and deposition demonstrate that the wave only adversely affects a 1000-ft width of shore, as measured from the shoreline, inland toward the interior marshes. Lagoons, bayous, and marshes inland of this zone do experience some water level oscillation, but here the effects have been dampened to the point that erosion and desposition are nearly nonexistent. For example, the great bulk of Lena Lagoon is relatively free of transverse wave processes. The reason for the lack of deep penetration of the wave is the "bayou effect." The intensity of the transverse wave is a function of the restricted nature of the MRGO (as outlined earlier in this chapter). The more restricted the waterway is, the greater the wave will be. If any source of water exists outside of the waterway, this water will provide an additional flow supply, thus reducing the wave height. A vivid example of this process is shown in Figure 18.

Degree of Erosion

Shoreline Erosion

Low altitude, vertical photographs from 1965 and 1981 were directly compared to attain an overall estimate of erosion on the MRGO northeast shore from Bayou Bienvenue to Bayou La Loutre. The method used incorporated an accurate positioning of the MRGO project canal as depicted on USACE charts (USACE 1982a), an assessment of those shoreline segments that were roughly linear in 1965, and a direct measurement from those 1965 shoreline segments to newly eroded positions by 1981 (USACE 1982a). The method resulted in direct shoreline recession measurements for 59% of the study area. The remaining 41% of the shoreline was so irregular in shape during 1965 (because channel dredging proceeded through areas dominated by numerous bayous and lakes) that it could not be subjected to analysis with any

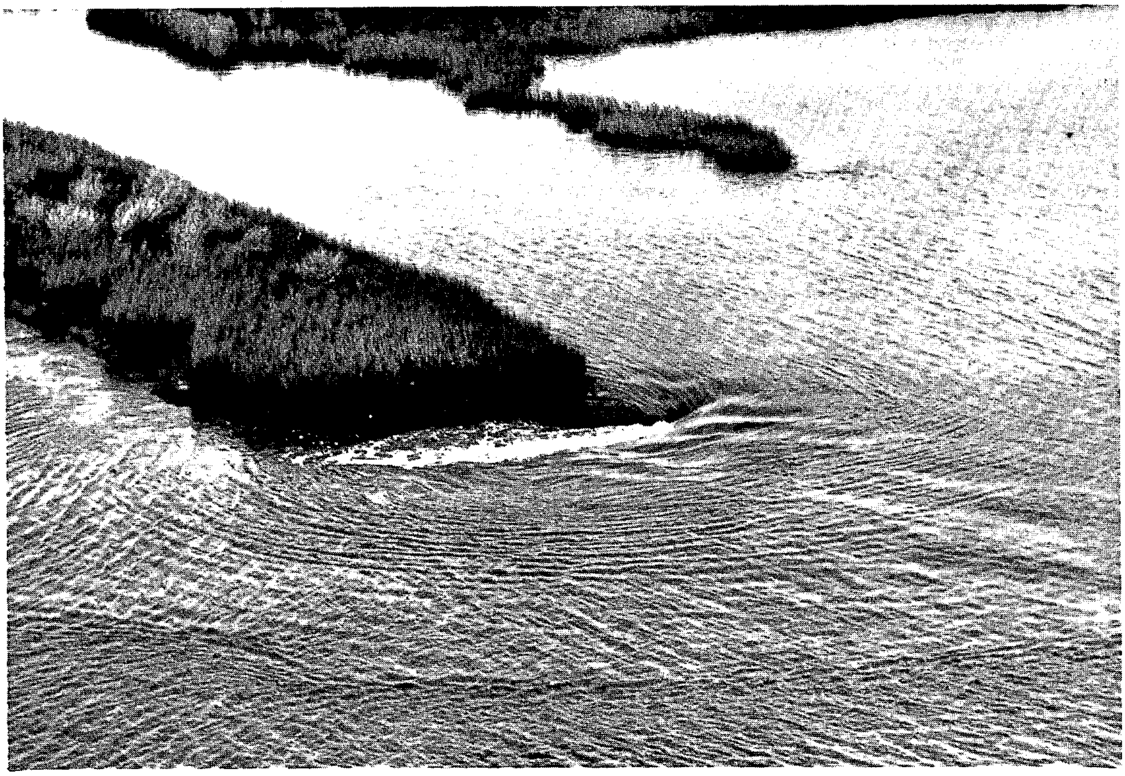


Figure 18. Low altitude oblique photograph of northeast shore of the MRGO at station 1095 as transverse wave from large displacement vessel causes drawdown. Note how bayou waters feed drawdown and thus mitigate wave activity in front of bayou.

accuracy. The results of the erosion analysis are shown in Figure 19. Erosion between 1965 and 1981 ranged from 100 to 600 ft of direct shoreline recession. Thus the rates of erosion over this 16-year period ranged from 6 to 36 ft/year. The mean erosion was 240 ft or 15 ft/year.

To further understand the nature and character of erosion, four areas were selected for detailed aerial photographic comparison using again the 1965 photography and a more contemporary set of 1983 photography. The Bayou Ducross-Bayou Villere area (Figure 20) provides a typical example of shore erosion which ranges an average of 12 to 18 ft/year. (Note how areas adjacent to bayous exhibit lesser amounts of erosion than the areas away from bayous.) The Proctor Point area (Figure 21) provides an example of a shore that is eroding uniformly at a low rate of 6 to 12 ft/year. Erosion also penetrates into preexisting bayous approximately 1000 ft, providing additional erosion away from the shore. The Lena Lagoon area (Figure 22) demonstrates severe erosion, in some locales as much as 36 ft/year. The MRGO waterway appears to have caused extreme erosion in this area, much greater than 36 ft/year, but this is an illusion. Much of this area was open lakes prior to MRGO construction. As can be seen, the MRGO waterway is in some locales 1500 ft wide, but only some 100 ft of this is due to direct erosion. The final example, the Bayou La Loutre area (Figure 23), typifies the erosion character in a low erosion (6 to 12 ft/year) section of the MRGO. Here erosion is basically uniform with very little penetration into interior areas. Bayou La Loutre has widened, but this is partly because it is a dredged waterway with an attendant amount of associated crew boat traffic.

These four examples of erosion provide a general framework for further development of the causal relationships between erosion factors and shoreline types. These further detailed relationships will be discussed later in this chapter.

Channel Stability

Viewing a cross section of the MRGO waterway provides insights into the nature of shoreline erosion. Six cross sections from three different areas have been prepared from USACE bathymetric and topographic data (USACE 1982a). Cross sections from the Lena Lagoon area (Figure 24) demonstrate vividly the relationship between channel character and shoreline erosion. The 1982 channel below -10 ft NGVD conforms nearly exactly to the project channel dimensions which were dredged in the early 1960s. The

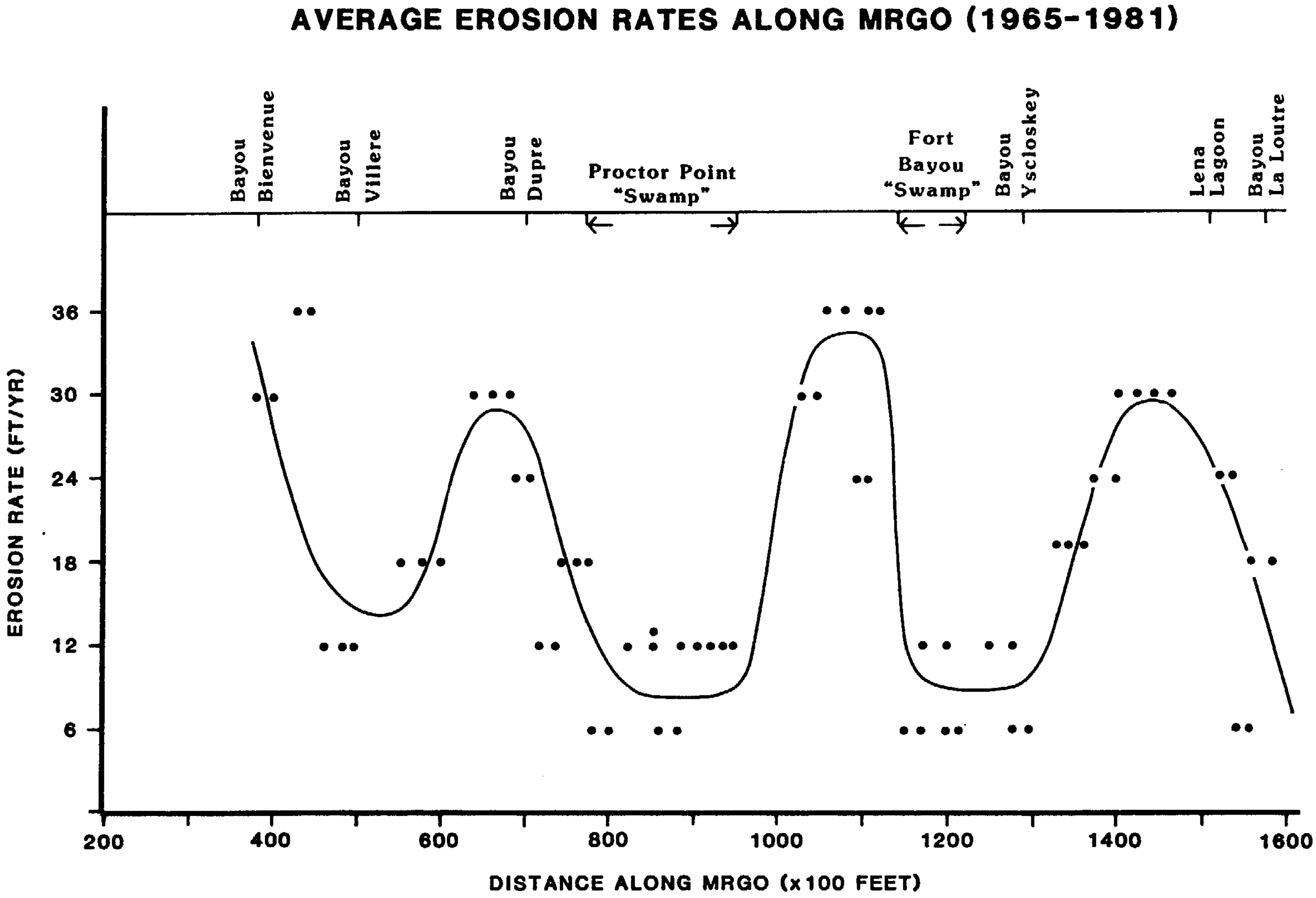


Figure 19. Average erosion rates along MRGO northeast shore from Bayou Bienvenue to Bayou La Loutre as determined from 1965 and 1981 aerial photograph comparison. Dots represent actual measurements. Curve outlines general erosion pattern.

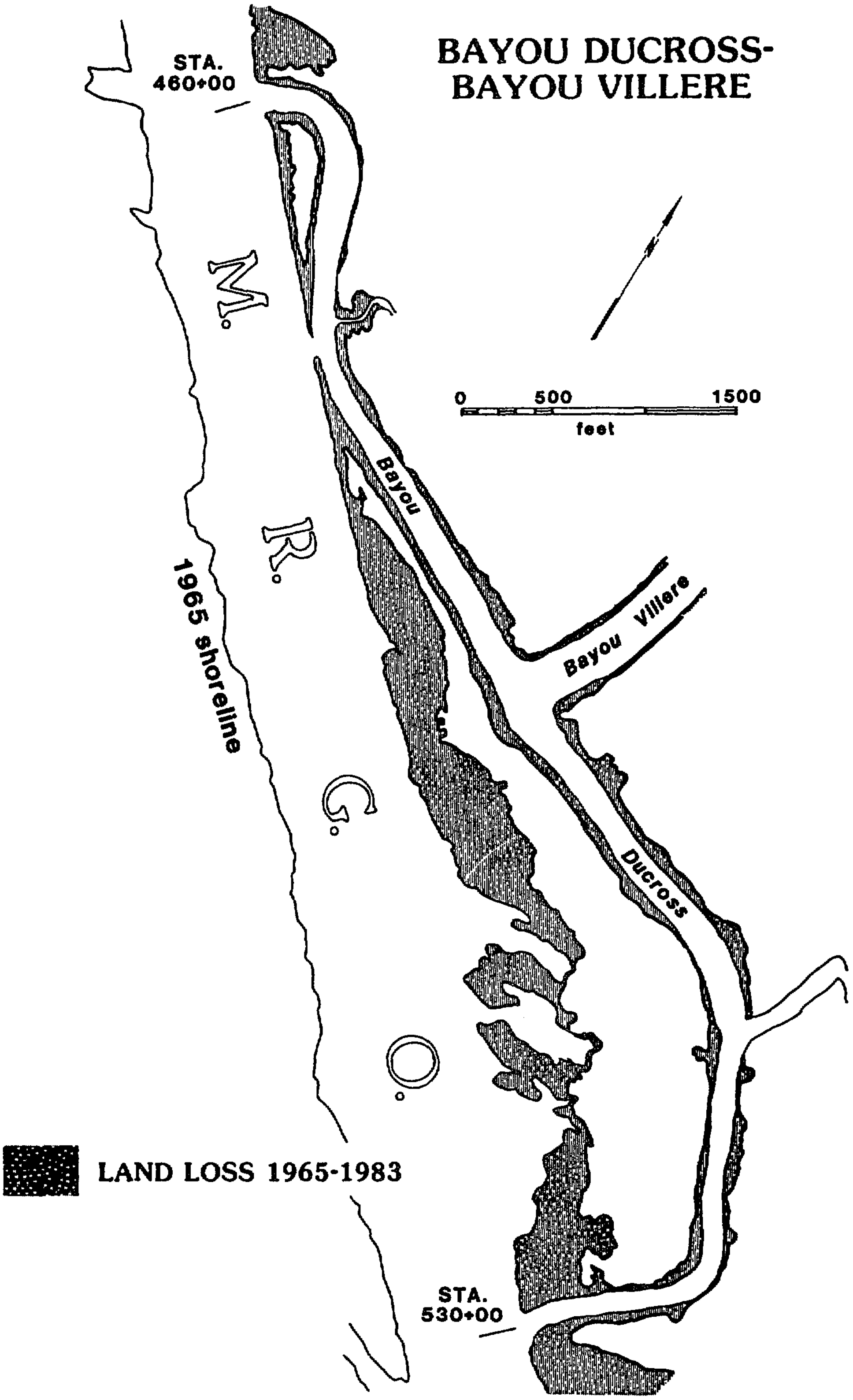


Figure 20. Erosion of MRGO northeast shore in Bayou Ducross - Bayou Villere area between 1965 and 1983 as determined from aerial photography.

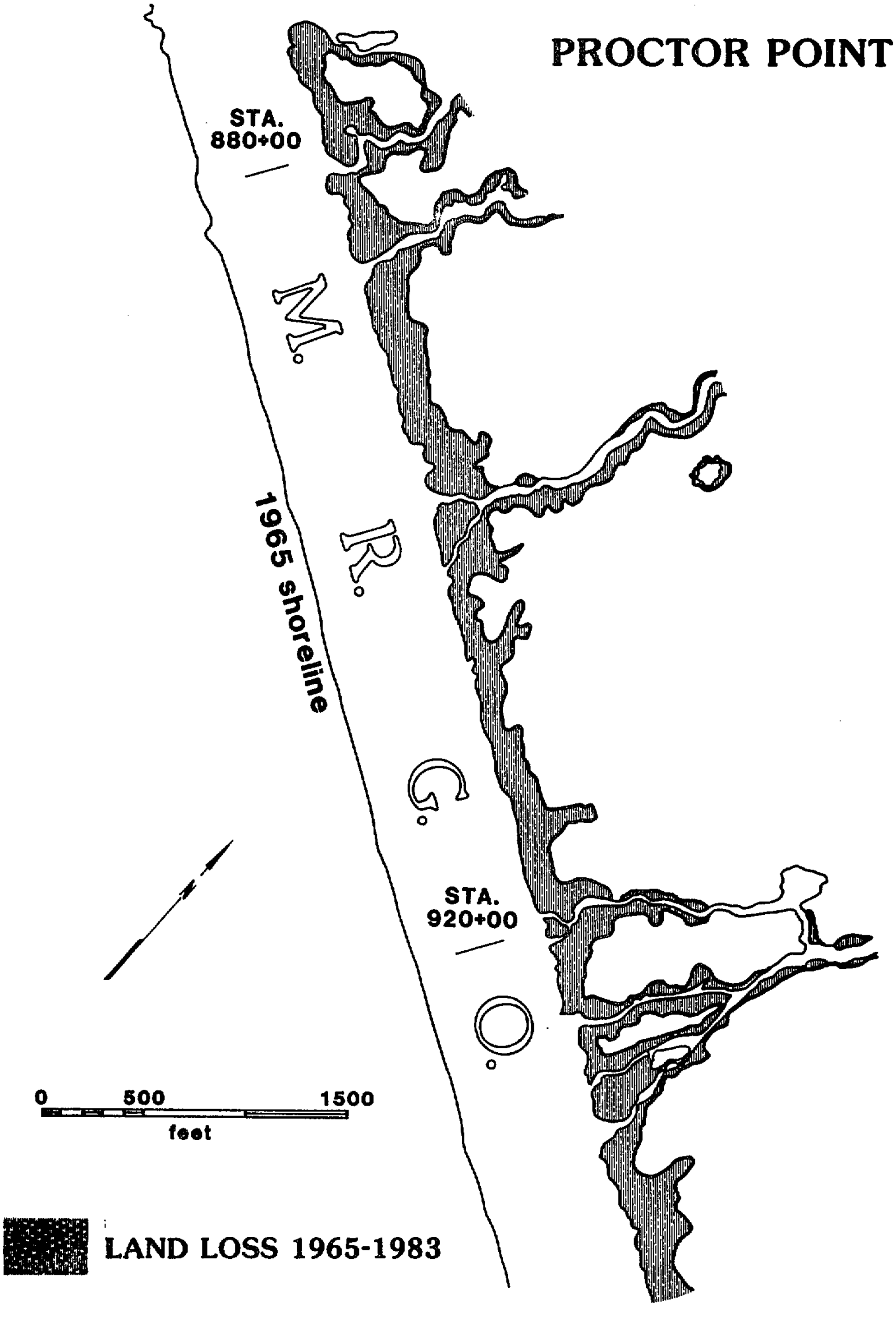


Figure 21. Erosion of MRGO northeast shore in Procter Point area between 1965 and 1983 as determined from aerial photography.

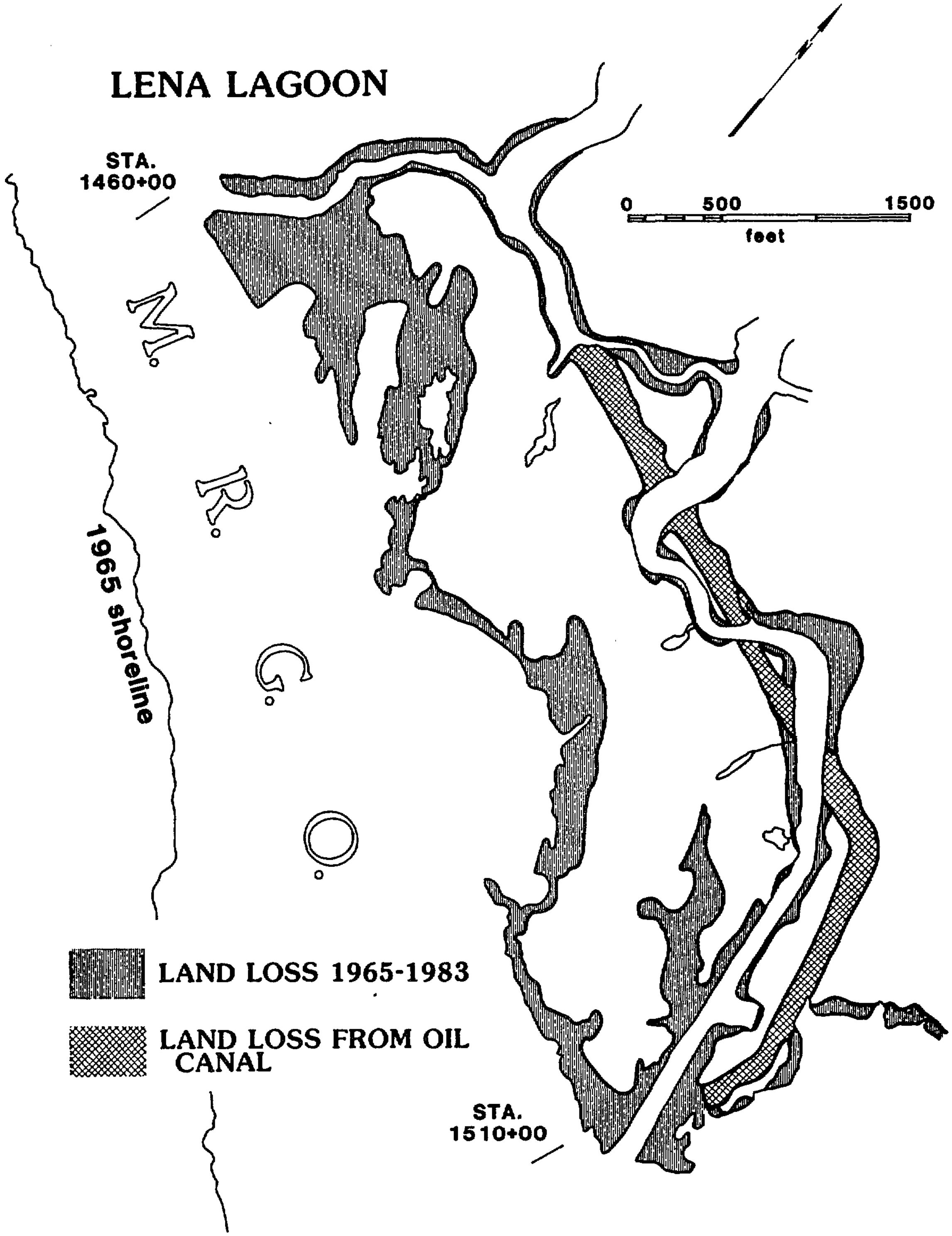


Figure 22. Erosion of MRGO northeast shore in Lena Lagoon area between 1965 and 1983 as determined from aerial photography.

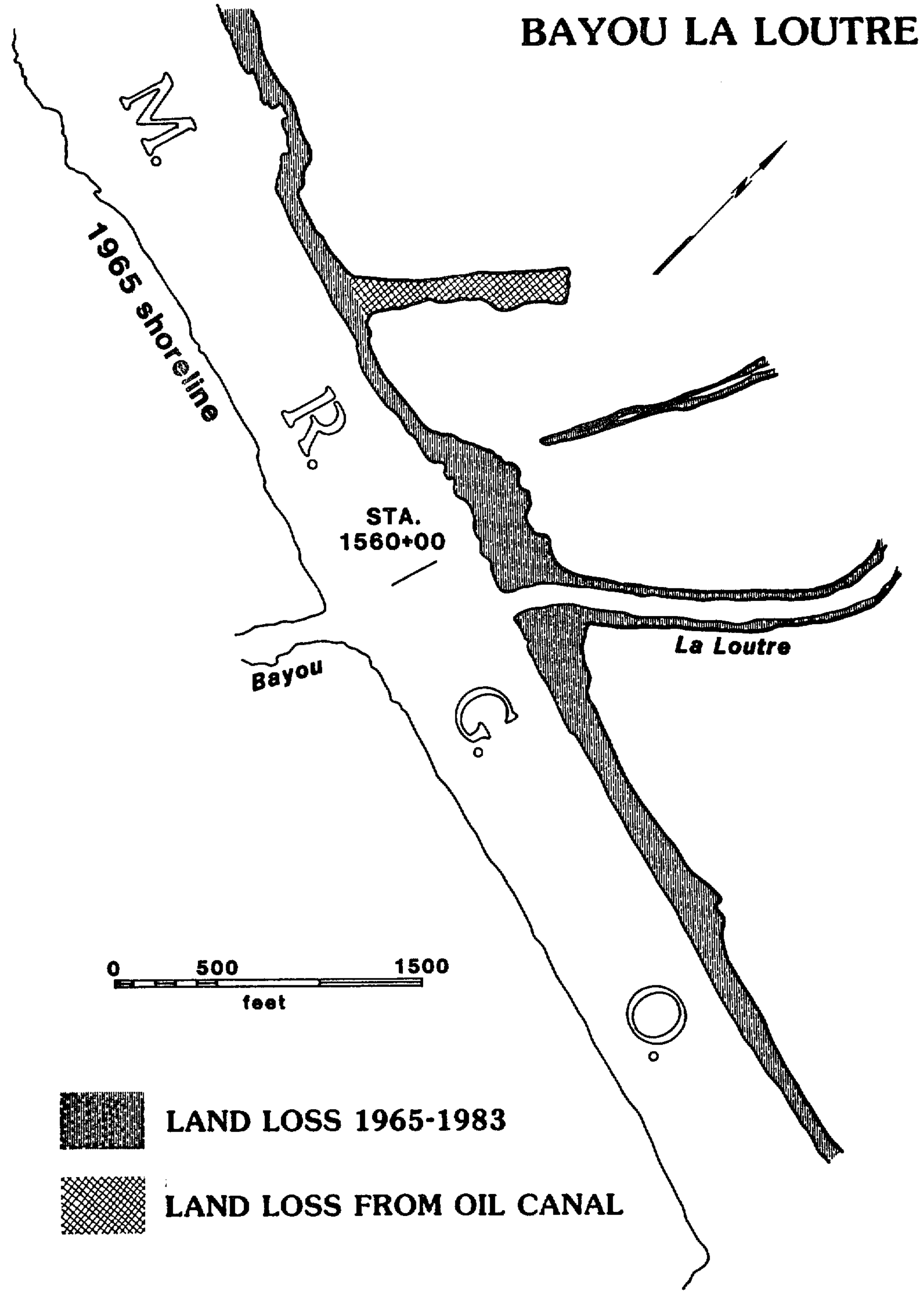


Figure 23. Erosion of MRGO northeast shore in Bayou La Loutre area between 1965 and 1983 as determined from aerial photography.

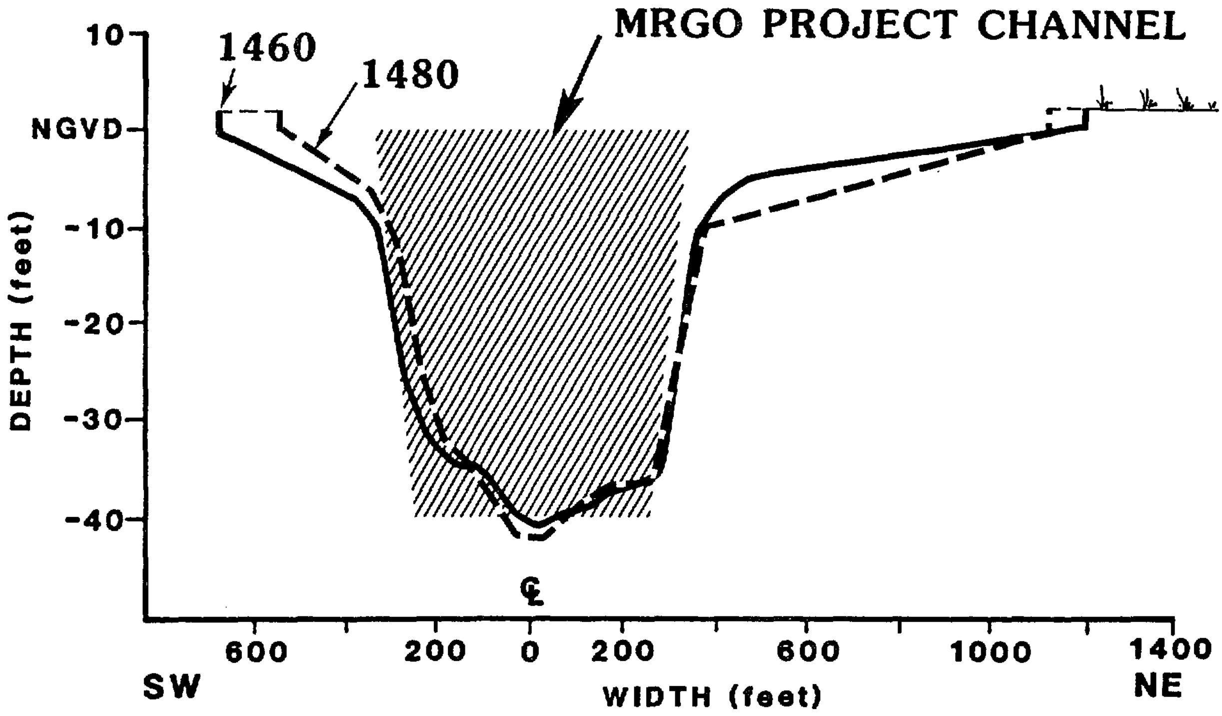


Figure 24. Typical MRGO cross sections in Lena Lagoon area (stations 1460 and 1480). November 1981 shoreline and July 1982 hydrography (USACE 1982a). Last maintenance dredging in 1972.

channel base is somewhat irregular, ranging from -36 to -42 ft NGVD. This is expected since it is known that shoaling and maintenance dredging are periodic phenomena in the landcut. Above -10 ft NGVD there is a broad, gently sloping "bench" leading up to marsh level on the northeast shore; this "bench" is where the erosion lies. In short, there exists an extreme dichotomy in erosion potential between the upper 10 ft of channel and the channel below 10 ft. The reason for the difference is twofold. The first and most obvious reason is that the upper section experiences extreme erosion potential from ship wave activity; the second relates to soil character and subsurface geology. The upper 10 ft in this section (as well as in 90% of the rest of the study area) is comprised predominantly of marsh substrate, better known as "peat." As anyone who has walked in the marsh knows, this material is extremely loose (Table 1). Below -10 ft the geologic strata abruptly becomes prodelta, intradelta complex, and interdistributary. None of these materials has any appreciable peat component; all are low water content and are high-to-moderate in strength (Table 1, Figures 3a and 3b). The difference in character between the layer below -10 ft and that above -10 ft, both in terms of sediment type and erodability, clearly demonstrates that the upper layer is the problem area. Restoration and protection measures, if applied, should be concentrated on the upper layer only.

The Bayou Ducross-Bayou Villere area provides a second view of the erosion situation (Figure 25). Here we find a very similar situation to that found in the Lena Lagoon section. The upper 10 ft is the area of erosional impact. As in the Lena Lagoon area, the contrast between the upper and lower layers is due primarily to variations in subsurface strata. Also note that an interesting anomaly exists in the Bayou Ducross-Bayou Villere area. The true channel location is skewed approximately 100 ft to the northeast of the assumed correct project channel position. It appears as if the channel has shifted since MRGO construction. From a process point of view this is highly unlikely; what has probably happened is the Corps has built the channel 100 ft too far to the north.

The final cross sections presented are from the Bayou La Loutre area (Figure 26). Below -10 NGVD the channel has remained stable. The upper 10 ft of the section is also stable. In the La Loutre area, there exists a relatively unique situation of shoreline stability. Here, the upper layer is not predominantly peat; it is comprised of natural levee (Figure 3b), a material of very high strength (Table 1). Unfortunately, natural levee is a minority substrate on the MRGO, and as such, the La Loutre erosion

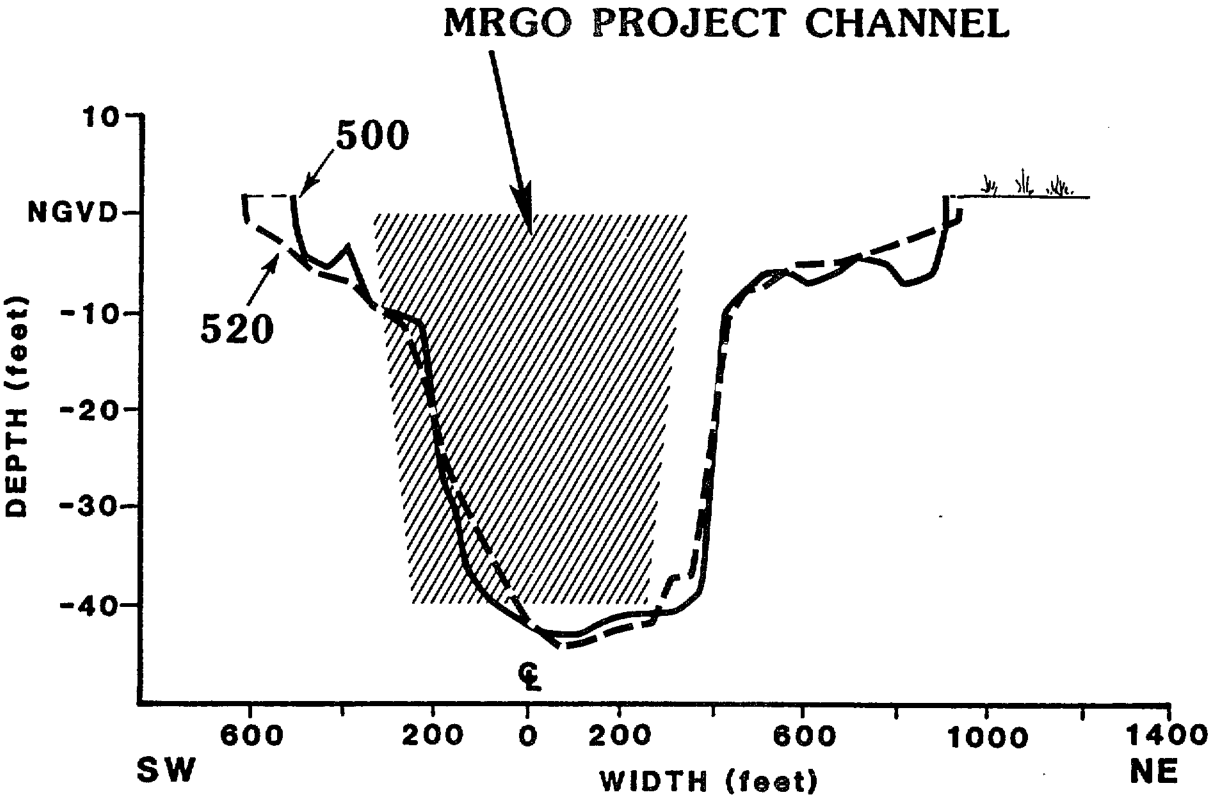


Figure 25. Typical MRGO cross sections in Bayou Ducross - Bayou Villere area (stations 500 and 520). November 1981 shoreline and July 1982 hydrography (USACE 1982a). Last maintenance dredging in 1972.

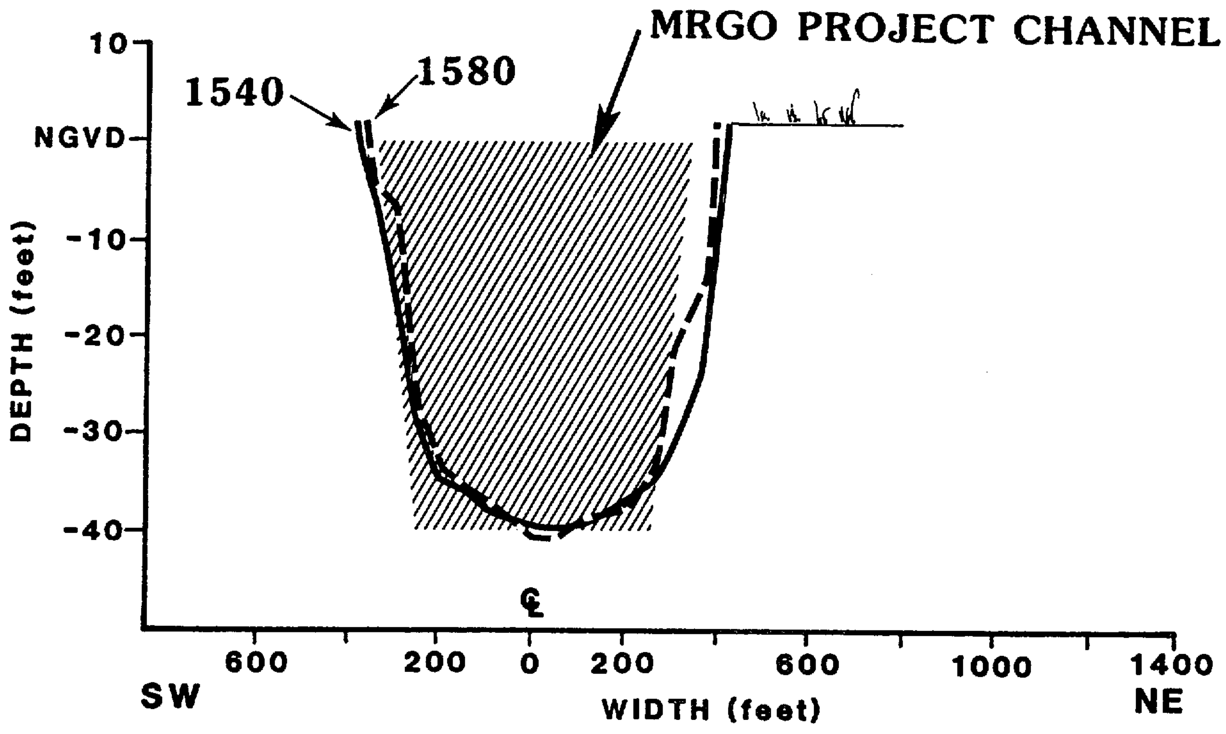


Figure 26. Typical MRGO cross sections in Bayou La Loutre area (stations 1540 and 1580). November 1981 shoreline and July 1982 hydrography (USACE 1982a). Last maintenance dredging in 1976.

character serves only as a unique contrast to the overwhelmingly drastic erosion which exists in the bulk of the peaty areas along the MRGO.

Volume of Erosion

The volume of substrate eroded from the MRGO northeast shore is easily calculable given that the erosion rates have been determined and that the vertical character of erosion has been identified. Further, comparing the results of a volume calculation to the known amount of maintenance dredging in the region allows for an understanding of the overall nature of erosional and depositional processes in the MRGO.

The method and results of shoreline erosion calculations have been presented earlier in this chapter. The length of shore affected by the various erosion rates is presented in Table 7; thus the surface area of sediment removal is known. Vertical erosion is assumed to always develop at the -10 ft NGVD level at the canal wall. As the marsh recedes, a triangular shaped wedge is removed. When this vertical erosion concept is applied to the actual shoreline erosion values, it is seen that 9,330,000 yd^3 have been eroded from the study area's northeast shore between 1965 and 1981 (Table 7). Thus the average annual rate of erosion is 583,000 yd^3/year.

The annual maintenance dredging volume in the study area is 1,064,000 yd^3/yr. A direct comparison of erosion and dredging reveals that shore erosion accounts for 55% of the shoal material in the canal; therefore, the remaining 45% of dredge material is thus far unaccounted for. Other sediment sources must account for the remaining 478,800 yd^3/year. These sources may be (1) material eroded from the southwest shore, (2) sediment carried into the canal on flood tide, (3) material tidally transported into the canal from Lake Borgne, and (4) sediment brought to the canal through wave action or tides from the interior marshes. The interior marshes of the study area have given way to 3,577 ac of open water between 1955 and 1978 (Table 3). It is very likely that sediment associated with this land loss has made its way into the canal and is now recognized as material removed during maintenance dredging.

Shoreline Character

Soil type plays a major role in determining erosion character and rates. Ship wave processes are the dominant agent of erosion, but such factors as organic content,

Table 7. Erosion of Northeast Shore of MRGO Between Bayou Bienvenue and Bayou La Loutre.

1965-1981 SHORE RECESSION INTERVAL (ft)	EQUIVALENT EROSION RATE (FT/YEAR)	SHORE[1] AFFECTED (ft)	ERODED[2] VOLUME (yd^3)
100	6	19,000	480,000
200	12	33,300	1,660,000
300	18	20,200	1,510,000
400	24	13,100	1,300,000
500	30	23,800	2,960,000
600	36	9,500	1,420,000

[1] Because of highly irregular shore in vicinity of lakes and bayous only 59% of shore was actually measured. The remaining 41% was estimated using ratios established on straight shores.

[2] Includes both marsh erosion and underlying substrate erosion which eroded in the fashion outlined in Figure 29.

SUMMARY: YEARS OF RECORD = 1965 to 1981

MEAN EROSION = 240 ft

MEAN EROSIO RATE = 15 ft/year

TOTAL ERODED VOLUME (1965 to 1981) = 9,330,000 yd^3

AVERAGE ANNUAL ERODED VOLUME = 583,000 yd^3/year water content, elevation, cohesive strength, and lithology directly determine the character and degree of the erosional response. One very important factor influencing erosion rates is the water content of the soil, as revealed in Figure 27. Water content in some locales reaches 900% of the dry weight of the soil. In other words, soil conditions in these areas are typified by 9 parts water and 1 part other dry ingredients such as peat or clay. Water content in general proves to be a controlling factor, where zones of high water content also are zones of very high erosion, and zones of low water content tend to be zones of low erosion; however, anomalies do exist.

In order to fully explain the relationships between soil types and erosion patterns, a classification system that includes the categories of soft marsh, firm marsh, and swamp (Figure 28a and 28b) has been formulated. Soft marsh is typified by high water content, high organic concentration, low elevation, and a correspondingly high erosion rate. Firm marsh is typified by low-to-moderate water content, low-to-moderate organic concentration, a slightly higher elevation, and a correspondingly lower erosion rate. Swamp soil is typified by a high water content, high organic concentration, low elevation, numerous stumps and logs, and a correspondingly low erosion rate. Each of these three zones is discussed in detail below.

Soft Marsh

Soft marsh areas are those most vulnerable to ship wave processes. Here, highly saturated peat predominates. Two layers of peat are common: (1) an upper 2- to 4-ft-thick fibrous peat layer comprised of an intact root mat and (2) a lower detrital peat layer down to -10 ft comprised of decomposed fragments of plant material. This layering in soft marsh allows for ship wave attack at the layered interface and a predictable sequence of erosion events (Figure 29). Wave drawdown and return flow during large displacement ship passage commonly undermines the fibrous layer, leaving this layer precariously suspended without any underlying support (Figure 30). Undermining proceeds until the upper layer succumbs to gravity forces, fractures, and drops as a free block (Figure 31). These fractured blocks of fibrous peat range in size from 1 ft^2 and 1 ft thick to 4 ft^2 and 2 ft thick.

Once fractured, these blocks are vulnerable to transport through subsequent ship wave activity. Some are tossed back onto the shore during transverse wave return flows; some are carried into the MRGO channel during transverse wave drawdowns. Once in

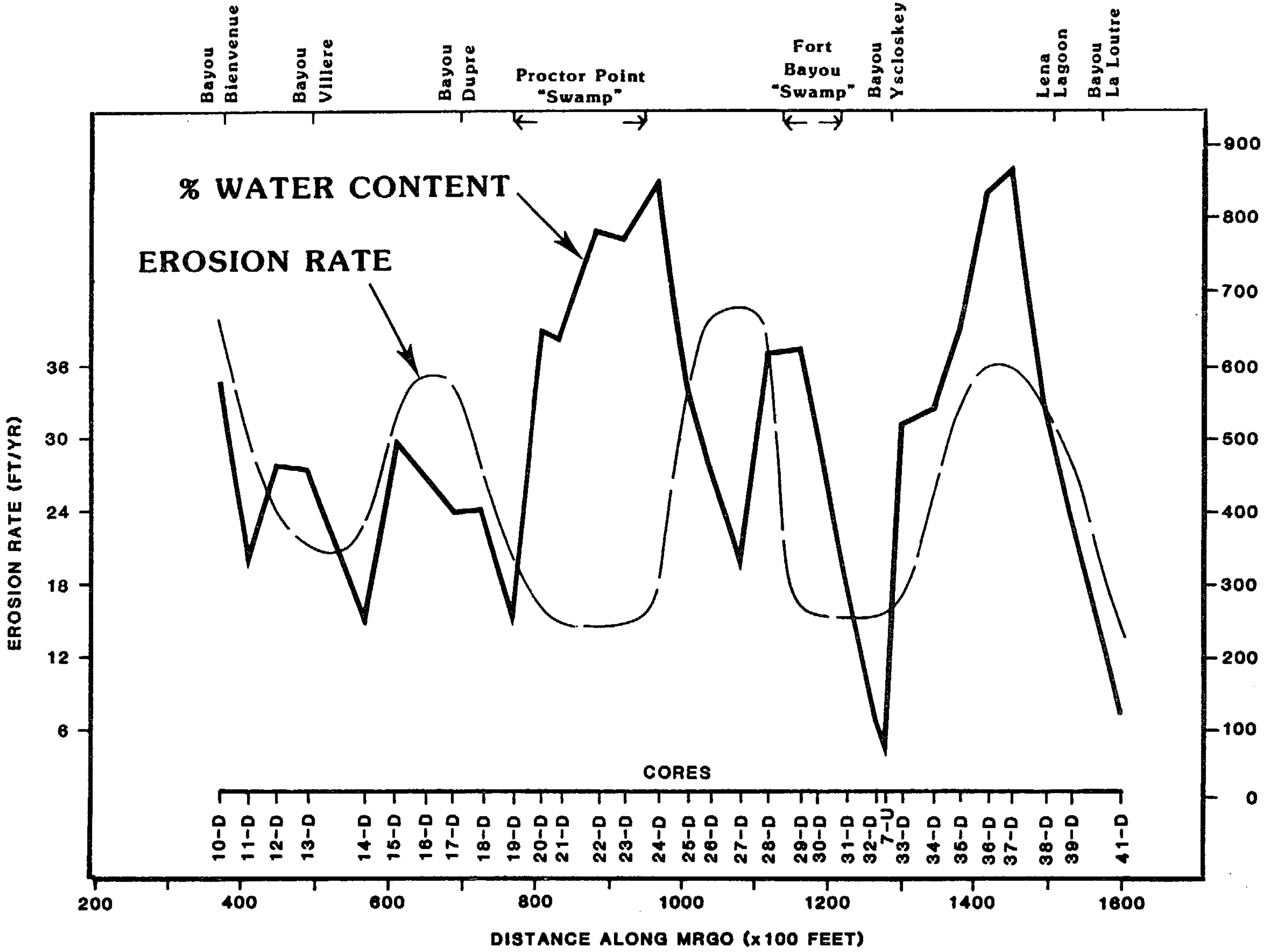


Figure 27. Distribution of soil water content along MRGO between Bayou Bienvenue and Bayou La Loutre. Water content values are percent dry weight of samples from upper 5 ft of sediment cores (prepared from core information provided by Kolb 1958). Erosion rate curve is superimposed for comparison.

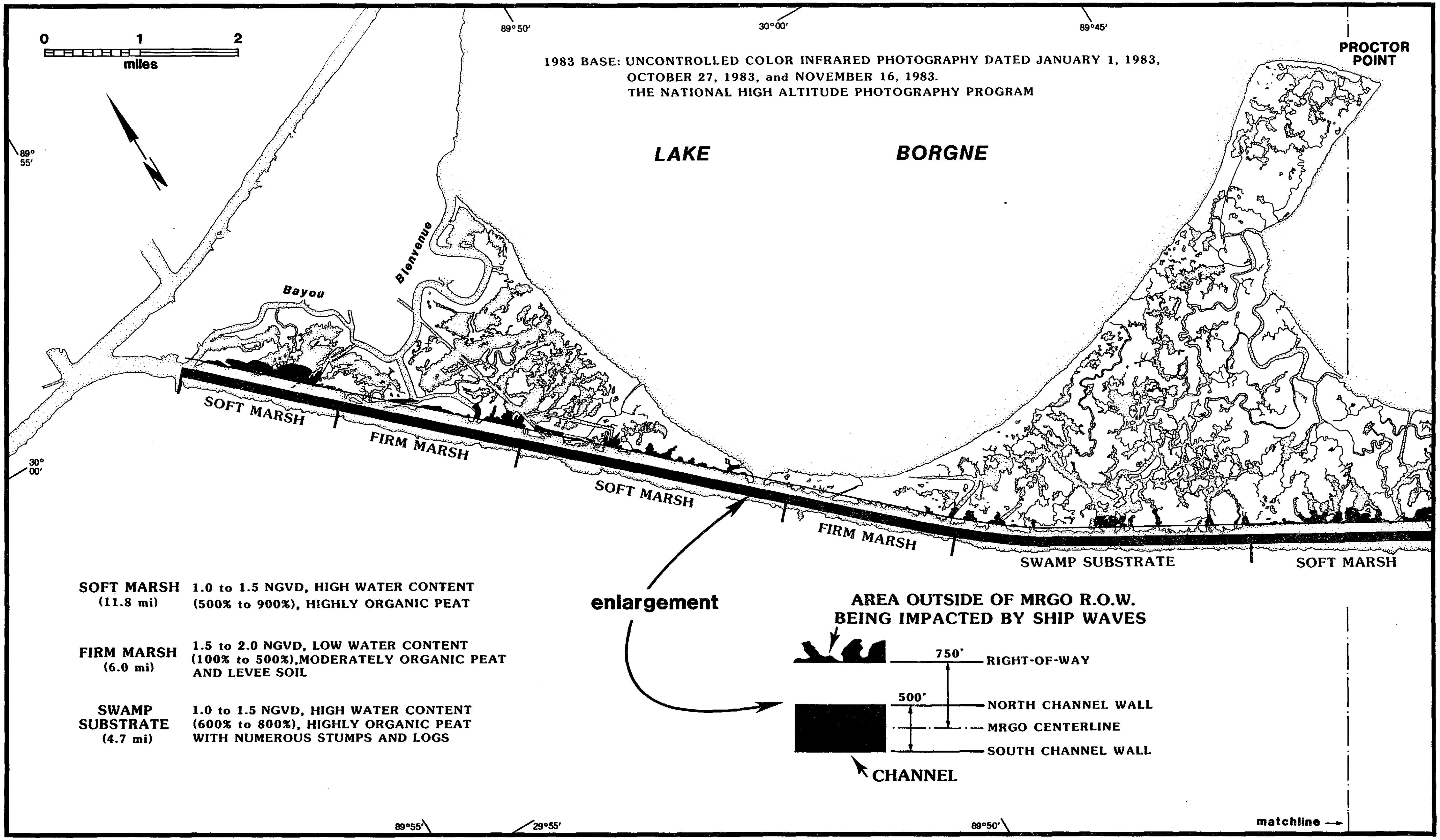


Figure 28a. Distribution of soft marsh, firm marsh, and swamp substrate along MRGO northeast shore.

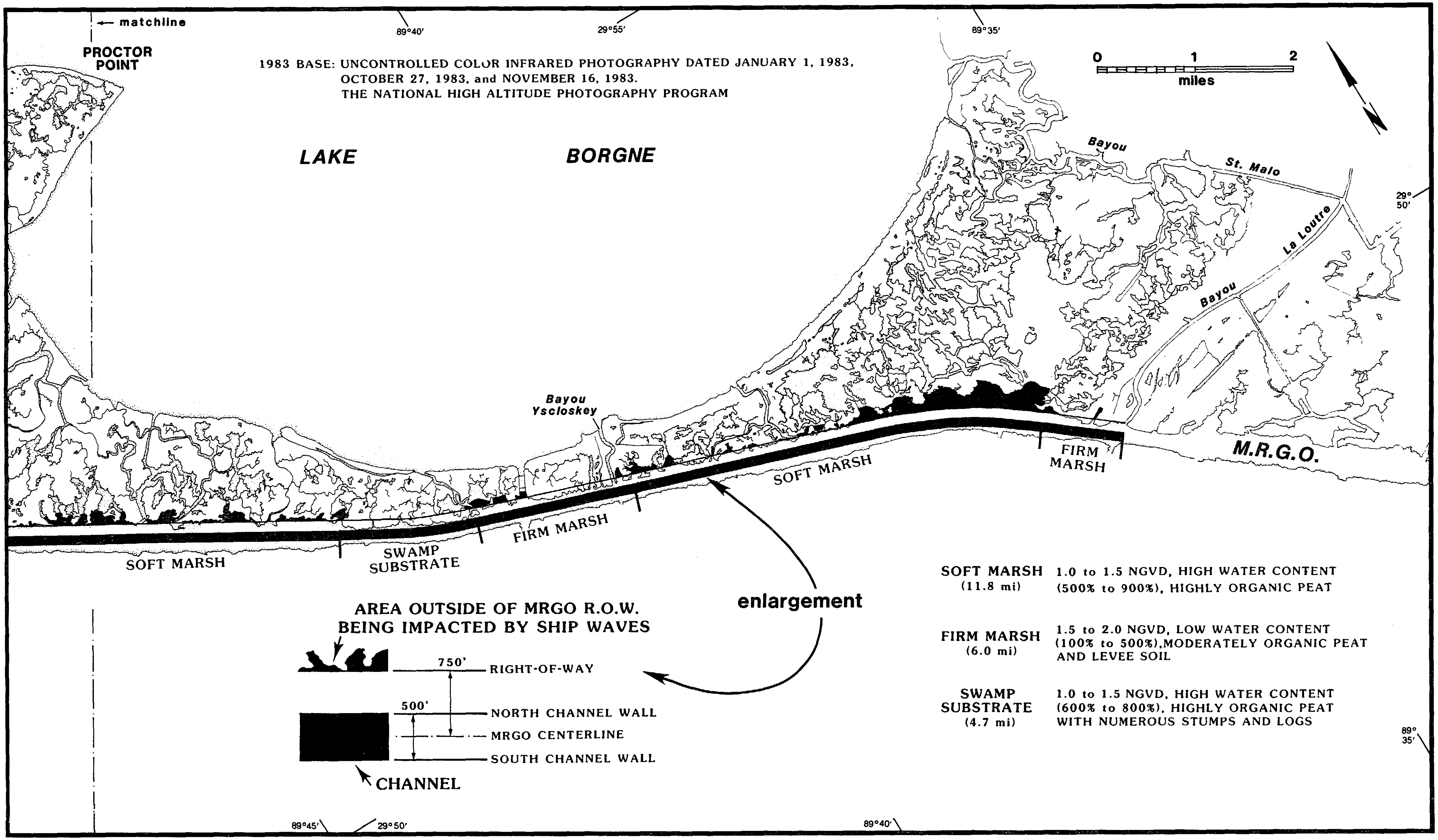


Figure 28b. Distribution of soft marsh, firm marsh, and swamp substrate along MRGO northeast shore.

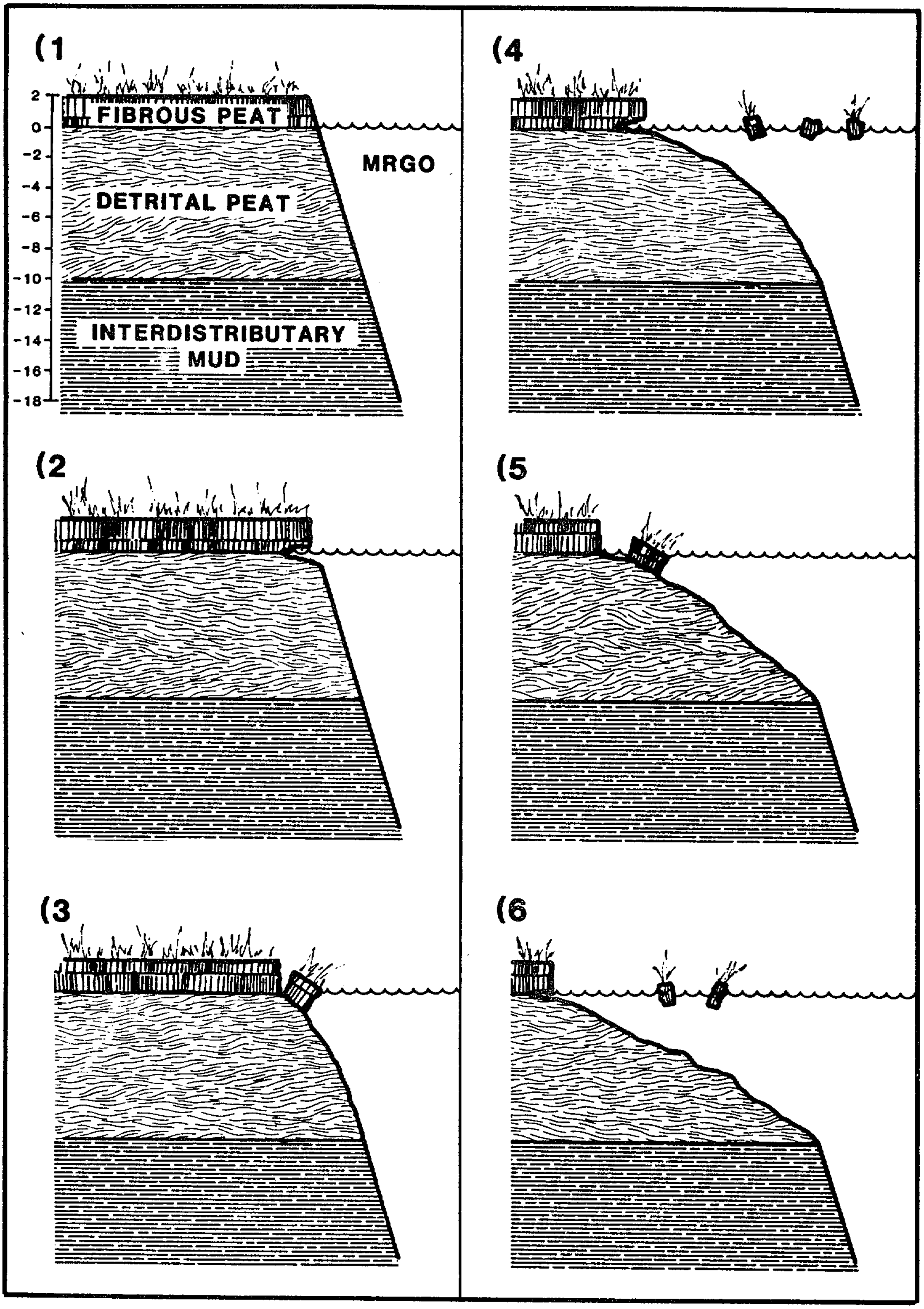


Figure 29. General sequence of erosion processes in soft marsh areas of MRGO northeast shore.

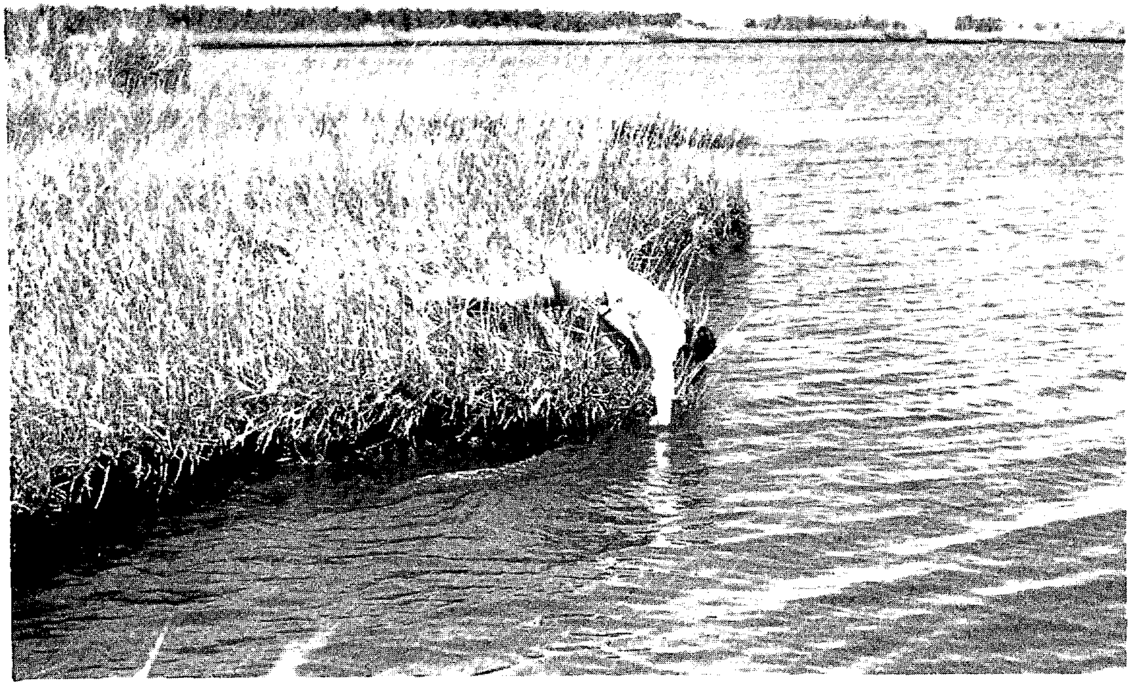


Figure 30. Undercutting of soft marsh substrate. Person is demonstrating degree of undercutting by extending forearm horizontally into void below root mat.

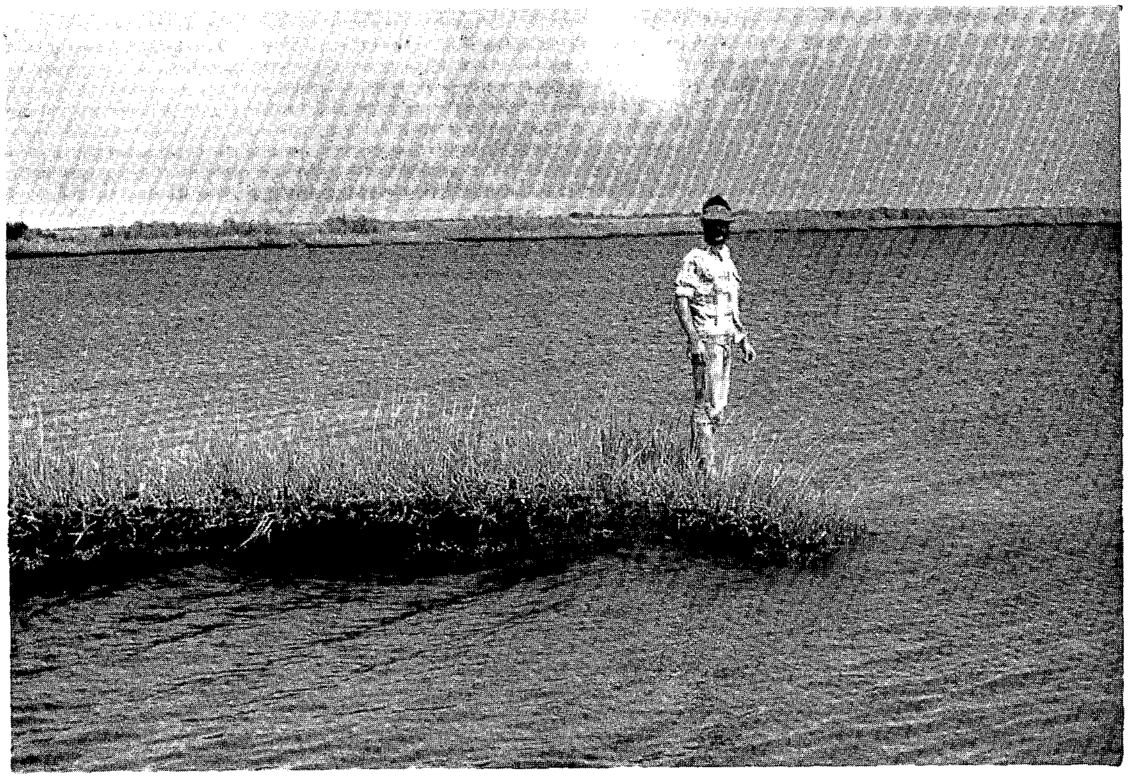


Figure 31. Failed marsh block in soft marsh area. Person is standing on fracture zone where marsh block has been undercut by ship waves and has fallen under its own weight.

deeper water, some blocks will float and be carried by tides to other locations; some will sink to the channel bottom. Shrimp fishermen have reported numerous smaller blocks caught within their nets while fishing in MRGO waters.

Once the blocks have been subjected to hydraulic transport, they undergo a transformation into a rounded form termed "peat balls." Currents cut away at their sharp block form and if currents are severe enough, as in transverse wave processes, they tend to roll along the shallows adjacent to shore. Any remaining vegetation is stripped from the block and the corners are rounded.

Numerous peat balls can be seen littering the bank in soft marsh areas. Those that are not lost through the MRGO channel are eventually tossed shoreward by ship waves into recessed coves along the MRGO shore. Some coves receive numerous influxes of these materials resulting in a slight elevation buildup. Figures 32 and 33 show two freshly deposited zones. Peat balls tend to accumulate until the substrate is built up to 4 ft above the original marsh level. Eventually the higher elevations are pioneered with woody vegetation. One area measured showed woody vegetation to grow in excess of 9 ft above the peat ball substrate. These "canal rim" zones generally extend 100 ft inland from the shore. Because of the elevational buildup, canal rim areas tend to dewater and compact the underlying substrate, providing a temporary natural spoil bank that tends to retard future erosional episodes.

Irregular shorelines typify the soft marsh areas. The weak substrate is highly vulnerable to channeling by transverse wave processes. Both drawdowns and return flows rush through any weak zones provided by former tidal creeks or fractures in the substrate. Once flows have found a path, intensified erosion ensues. Channels enlarge; some extend inland 1000 ft, others only a few feet. The net result is a shoreline characterized by numerous islands and channels jutting out in irregular form (Figure 34).

Firm Marsh

Soils in firm marsh areas are generally of low-to-moderate organic content, low-to-moderate water content, and of slightly higher elevation. These soils are generally of two origins: (1) former levee complexes at or near the surface such as Bayou LaLoutre

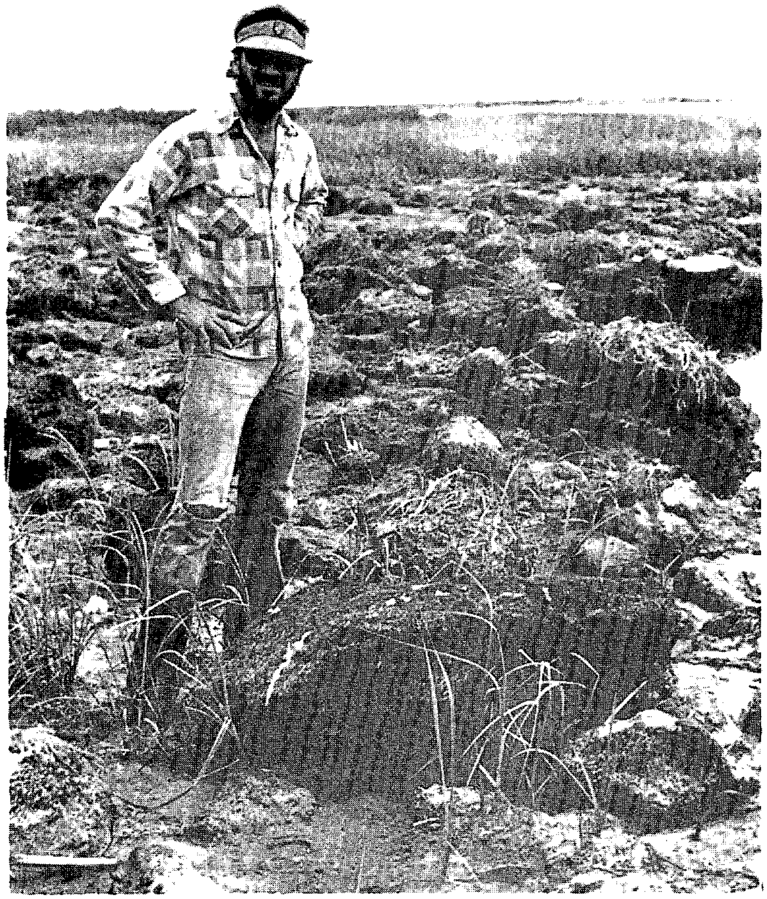


Figure 32. Large marsh block that has flipped onto marsh surface by a large transverse wave. Note numerous smaller blocks in background.

Figure 33. Marsh blocks deposited in cove by transverse waves.

Figure 34. Oblique low altitude aerial photograph of typically irregularly-shaped soft marsh MRGO shore. Note numerous cuts of various sizes and many irregularly shaped islands.

and Bayou Yscloskey, and (2) former major tidal creeks such as Bayou Ducross and Bayou Villere. Regardless of its origin, the firm marsh areas offer more resistance to large displacement vessel waves. These soils do not provide zones of weakness as do the soft marsh areas. Marsh blocks do not separate and channels rarely form. The erosion that does occur proceeds on a smaller scale. Only small clumps break away and most erosion proceeds on a grain-by-grain basis. Because of the firmer soil, peat balls and canal rims are rare, and the shoreline in general is very straight with few cuts and islands. A typical stretch of firm marsh shoreline is shown in Figure 35.

Swamp

The third and final shoreline form to be discussed is that comprised of swamp substrate. Nowhere along the entire MRGO are there any live swamps. There were some limited stretches of live swamp, primarily in the Proctor Point area, when the MRGO was built in the early 1960s. But these areas were all killed within a year or so after construction by the subsequent saltwater intrusion which destroyed their natural habitat. There are many miles of MRGO shore that are comprised of much older swamp substrate, though substrate derived from both historic and prehistoric swamp forests. These swamps died from natural saltwater intrusion associated with long-term subsidence long before MRGO construction. The net result is that numerous logs and stumps can be found just at or just below the surface in a total of 4.7 mi along the MRGO within the study area.

The soils associated with these areas are generally comprised of very high organic content and very high water content. Fortunately, these characteristics, which would commonly be associated with high erosion, are overshadowed by the fact that numerous stumps and logs are present. As a result, these areas are characterized by a very low erosion potential (6 to 12 ft/year).

The transverse waves from large displacement vessels cause significant drawdowns and return flows in these areas, just as they do throughout the rest of the shoreline. Loose debris is easily removed from around the stumps and logs (Figure 36). However, the stumps and logs eventually become entirely exhumed and remain as a natural form of riprap to prevent further erosion from occurring.

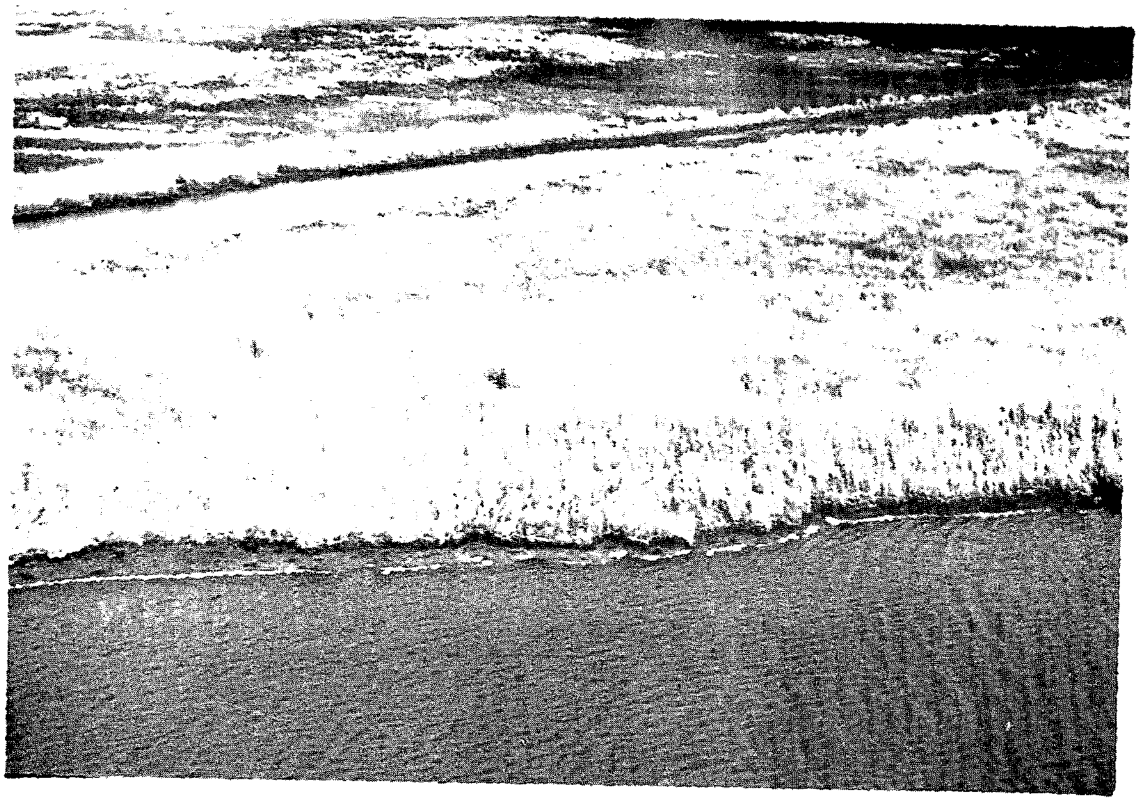


Figure 35. Oblique low altitude aerial photograph of typically straight-shaped firm marsh MRGO shore. This is station 725 where levee substrate provides slight elevation rise and support of roseaucane vegetation.

Figure 36. Swamp shoreline at station 870.

The stumps provide the greatest degree of erosional protection. Cypress is noted for its ability to resist rot, particularly if it has been covered with water and sediment. Even though many of the stumps along the shore may be as old as 500 years, the root systems are firmly attached in the substrate. Transverse waves have attempted in earnest to remove the stumps, but most remain intact in their growth positions (Figure 37). The net effect is for the stumps to reduce current flow, both during drawdown and return flow. Water level fluctuations are reduced and the shore is protected from severe erosion.

Figure 37. Transverse wave drawdown on swamp shoreline as large displacement vessel passes. Old stumps firmly implanted in adjacent shallow waters are providing a firm barrier to wave activity, thus shoreline erosion rate is relatively low in this area.

CHAPTER 5: SHORELINE PROTECTION MEASURES

Design Considerations

Ship Waves

The MRGO shoreline is subject to erosion from several physical processes which occur with the passage of ship waves. The tidal fluctuations on the MRGO contribute to the problem by allowing erosion to occur at various water levels. Ship waves are composed primarily of two parts: transverse and diverging. The transverse wave can be further divided into its principle components, the drawdown and return flow. It should be noted that wind-generated waves also occur on the MRGO, although these do not appear to cause significant erosion when compared to ship-related processes.

Shoreline erosion on the MRGO can be divided into two layers. The first of these is an erosion of the lower shoreline, or bench area, which becomes exposed during drawdown. The second is an erosion of the upper shoreline, which is the area from around mean water level to the marsh elevation. Since water levels fluctuate, it is difficult to define elevations of the upper and lower shore, and as such these are used as generalized terms.

During the passage of a large ship the lower shoreline is attacked first by the drawdown and return flow. As the drawdown occurs, water flows from the lower shoreline towards the center of the MRGO channel, causing erosion. Depending on tide level, water may also be drawn out of the marsh towards the channel. This can be a very turbulent and erosive process because of the head differential set up between the marsh and the channel. A similar differential causes hydrostatic pressures to be built up in the exposed bank, forcing water to leave the soil.

After the drawdown phase has been completed the return flow begins. From this point the water level along the shoreline will continue to rise until the original water level is exceeded. The return flow, being a flow of water back towards the shoreline, directly impacts both the lower shoreline and the exposed marsh bank. The diverging waves then begin to reach the shore as water elevation is at a maximum or mean level, continuing the attack on the upper shoreline.

Both the upper and lower shorelines must be considered in shoreline protection. Failure to protect the lower bank from erosion will eventually cause any upper bank protection to fail by undermining. In the Corps' test sections (to be discussed in detail) aprons were placed at the toe of the slope to prevent undermining. The use of a flexible apron allows settlement to occur without failure. The materials used for armoring the lower bank must have sufficient permeability and weight to prevent the hydrostatic uplift effect of the drawdown which can lead to failure.

Obviously the upper bank must also be protected to prevent the retreat of the shoreline. The protective works here are especially subject to impact forces of the return flow and diverging waves. Loosely placed materials must be large enough to resist these forces; otherwise materials used must be restrained from washout. A continuous structure would prevent the rapid movement of water from the marsh during drawdowns; however, the resulting pressure increase on the structure must be recognized.

Water Levels

Water-level variations on the MRGO must be considered to determine the range of elevations at which erosion will occur on the shoreline. Figure 4 shows that water levels can range from -1 ft to +5 ft NGVD. These levels are monthly minimums and maximums. Using the maximum size wave described earlier (4 ft drawdown, 2 ft return flow) the shoreline would need to be protected from -5 ft to +7 ft NGVD based on these water levels.

The placement of protection to the lower limit of -5 ft NGVD will be necessary to assure against failure. A flexible apron can be used on the lower shoreline to achieve this goal. In design, the apron would be placed above -5 ft NGVD and would be allowed to settle into place. The placement of protection to the upper limit of +7 ft NGVD must be considered in terms of its practicality. More description of soils and problems anticipated in building on these soils will be discussed in the foundation section; however, it is apparent that the higher a structure is built, the more construction and performance problems will be encountered. Likewise, the higher a structure is built, the greater the amount and costs of materials.

The most serious water-level consideration is whether wave overtopping of the structure will cause failure. The greater the height of the structure, the lesser the frequency at which it will be overtopped. It is impractical to build a structure to an elevation of +7 ft NGVD to assure against this occurrence, yet a lower level structure that is frequently overtopped will allow the marsh behind it to erode, subsequently causing the failure of the structure. The most logical procedure is to build the structure to an intermediate elevation between the marsh level and +7 ft NGVD (that is, +3 or +4 NGVD) and design against the erosive effects of the overtopping. Included would be protection on the back side to prevent against washout. It should be remembered that most ships are expected to cause return flows not exceeding 1 ft above still water level. To obtain a water level as high as +7 ft NGVD would require that a very large ship pass at extremely high water. The probability of these two events occurring simultaneously is low since there are typically only three or four oceangoing vessels per day using the MRGO and few of these are of very large displacement. Controls could also be placed on the passage of ships during extremely high water levels. The height to which structures are placed along the shoreline may ultimately be determined by what is feasible when actual field construction is begun.

Foundation Conditions

The soil characteristics of the northeast shoreline present serious complications in construction of shoreline protection. The uppermost layer is predominantly "marsh" soil and averages about 10 ft in depth. Marsh soils are composed largely of organic material with very high water contents and low cohesive strengths. These soils are subject to rapid compaction when loaded. Based on these descriptions it is apparent that the weight of any type of shoreline protection will be a controlling factor in application to this environment.

The major difference in characteristics of the northeast and southwest shorelines has resulted from the spoil deposition on the southwest side. The deposition of spoil on the southwest shoreline had several effects:

(1) The dredged material placed on the shoreline was more resistive to the wave action than the erosive marsh soil; so erosion was reduced.

(2) The weight of the dredged material caused the underlying marsh soils to be compacted.

(3) The dredged material increased the southwest shoreline elevations which also decreased erosion.

These facts must be taken into consideration when evaluating the application southwest shore Corps test sections on the northeast shoreline. The settlements of the Corps stone sections ranged around 1 ft on spoil deposits above precompressed foundations. It is obvious that settlements of such a section would be massive on the northeast shoreline. In addition, the elevations on the southwest shoreline are higher and there was simply better material available for the Corps to use in construction. In contrast, on the northeast shoreline the elevations are low and the only material immediately available is marsh soil.

Underlying the marsh soil in the region are the "interdistributary" and "intradelta complex" layers. These soils contain 80% clay with sand and silt deposits distributed throughout. Since the marsh soil has such poor characteristics, these lower geologic layers may prove to be useful in stabilization of structures on the surface. This stabilization would be accomplished by using pilings to reach through the 10 ft of marsh into the lower layers.

Shoreline Discontinuity

When the MRGO was first cut there was at least an approximation of a straight shore, even though it was intersected with bayous and lakes. But now, after some 20 years of erosion, the northeast shore is extremely irregular in nature with only a few sections remaining as straight. The shore is now typified by coves, cuts, lakes, major bayous, minor bayous and islands. This discontinuity provides a major engineering challenge if structural measures of erosion control are to be undertaken.

Clearly, some major intersecting waterways, such as Bayou La Loutre, Bayou Yscloskey, and Bayou Dupre, will have to be left open for navigation interests. Smaller bayous, creeks, and entrances into lakes should, however, be permanently closed. Doing so will reduce both saltwater intrusion and wave penetration into interior areas. More importantly, closing minor waterways will allow for structures to span greater reaches. In this regard, structures must be built across areas of variable topography and bathymetry. Designs of measures must incorporate these variabilities. Some areas may require dredging while some areas may require fill.

Critical Areas

As described in Chapter 4, the northeast shoreline within the study area is variable in character with differing degrees of erosion potential, ranging from 6 to 36 ft/year. Within this framework of erosion potential there have been three basic shoreline types identified: (1) soft marsh, 11.8 mi; (2) firm marsh, 6.0 mi; and (3) swamp, 4.7 mi. Swamp areas have proven to be the least vulnerable to erosion. The shore in these locales has held up remarkably well, given the intensity of the wave erosion process. Stumps and logs provide the presently observed relative shoreline stability, and the emplacement of a protective measure in these locales would probably harm the natural protection that the stumps and logs afford. Swamp areas should, for the most part, be left as is.

Firm marsh areas also provide some natural stability to the erosion process. It is debatable whether structural measures should be emplaced in these locales. Constructing erosional barriers would not, however, detract from the shore's natural ability to retard erosion. Selecting to protect the firm marsh areas will have to be based on cost/benefit relationships.

Soft marsh areas provide little resistance to the wave erosion process. Erosion rates in some locales are as high as 36 ft/year. There is no doubt that these areas need protection desperately.

U. S. Army Corps of Engineers MRGO Test Sections

Design and Cost

The USACE recently constructed and evaluated the performance of six erosion control test sections on the MRGO. The sections were located between stations 475 and 501 on the spoil bank side (southwest shoreline). The Corps conducted surveys both before and after construction to measure movements and settlements. Observations were made periodically to check for structural failures as well as causes of these failures. Two of the sections showed satisfactory results while others failed completely (USACE 1983b).

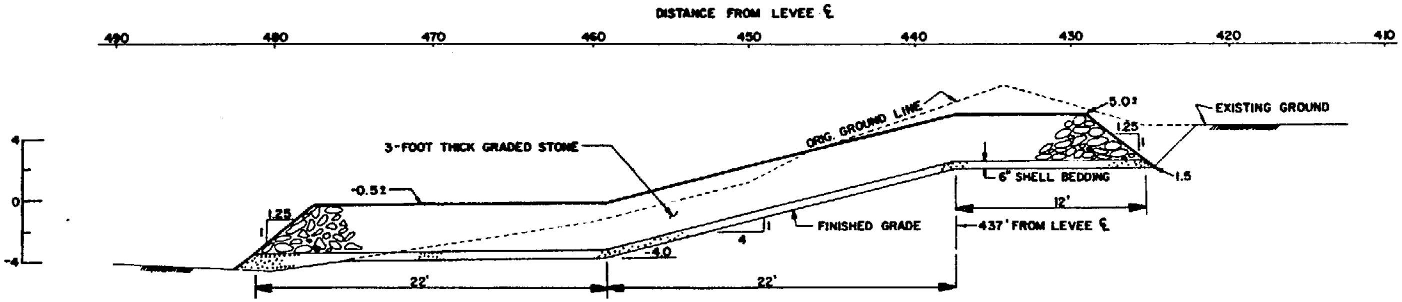
The construction plans called for following the alignment of the shoreline. However, during construction a straight alignment was maintained by cutting high areas and filling low areas with shell. The first two sections consisted of a 36-in layer of graded stone on 6 in of shell bedding and a 36-in layer of this same stone on filter cloth. The average weight of each stone is 900 lbs, which was appropriately sized to resist forces from a 4-ft wave. The sections were each constructed with a 20-ft-wide apron extending from approximately -4 ft NGVD to -1.0 or -0.5 ft NGVD (Figure 38). The purpose of the apron is to prevent the waves from undermining the embankment, which was constructed with a 1:4 slope up to a crest elevation of +5 ft NGVD. At this elevation, overtopping by the waves is unlikely, although some did occur. The Corps was concerned about this condition causing failure on the back side; however, observations have indicated that the overwash has built up the low areas in back of the structure by depositing sediments.

Figure 39 shows a very large flat rock used with diameters as large as 3 ft. Figure 40 shows the straighter alignment with the apron slightly exposed at low tide. The filter cloth used in the tests had an equivalent opening size (EOS) of 50 and less than 10% of open area (this was the only fabric used in the testing). The Corps estimated the costs of materials and construction for the rocked shell and filter cloth sections at $274 and $279/linear ft, respectively.

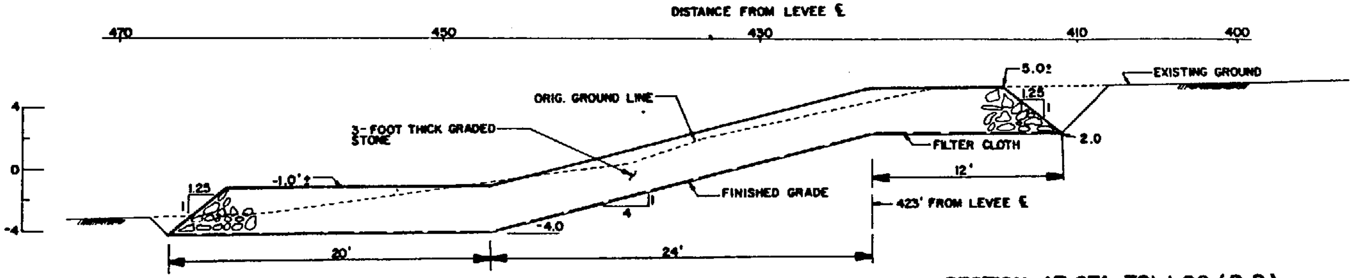
The third section tested by the Corps consisted of 4-in-thick interlocking concrete blocks called "Trilock" placed on filter fabric (Figure 41). The 12-ft-wide apron was constructed at elevation -4.0 ft NGVD with a 1:4 embankment slope and a crest at +4.0 ft NGVD. The estimated cost of this protection was $372/linear ft.

The forth and fifth test sections consisted of 18 in of grade "C" stone on 6 in of shell and on filter cloth (Figure 42). The average weight of the stone is 100 lbs. These sections were constructed similarly to sections 1 and 2. The cost of these armored shell and filter cloth sections were estimated at $135 and $147/linear ft, respectively.

The sixth type of protection tested was government furnished, articulated concrete mat on filter cloth constructed very similarly to the concrete block section (Figure 43). The mats were approximately 3 in thick, 4 ft long, and 14 in wide and were tied together by wires passing through the concrete. The estimated cost of the articulated concrete mat was $233/linear ft.



SECTION AT STA. 477 + 00 (A-A)
3-FOOT OF GRADED STONE ON 6 INCHES OF SHELL
FROM STA. 475 + 00 TO 479 + 00



SECTION AT STA. 781 + 00 (B-B)
3-FOOT OF GRADED STONE ON FILTER CLOTH
FROM STA. 479 + 00 TO 483 + 00

Figure 38. Design of test sections 1 and 2, MRGO foreshore protection project (USACE 1982b).

Figure 39. Photograph taken 27 March 1984 of test sections 1 and 2, MRGO foreshore protection project.

Figure 40. Photograph taken 27 March 1984 of test sections 1 and 2, MRGO foreshore protection project.

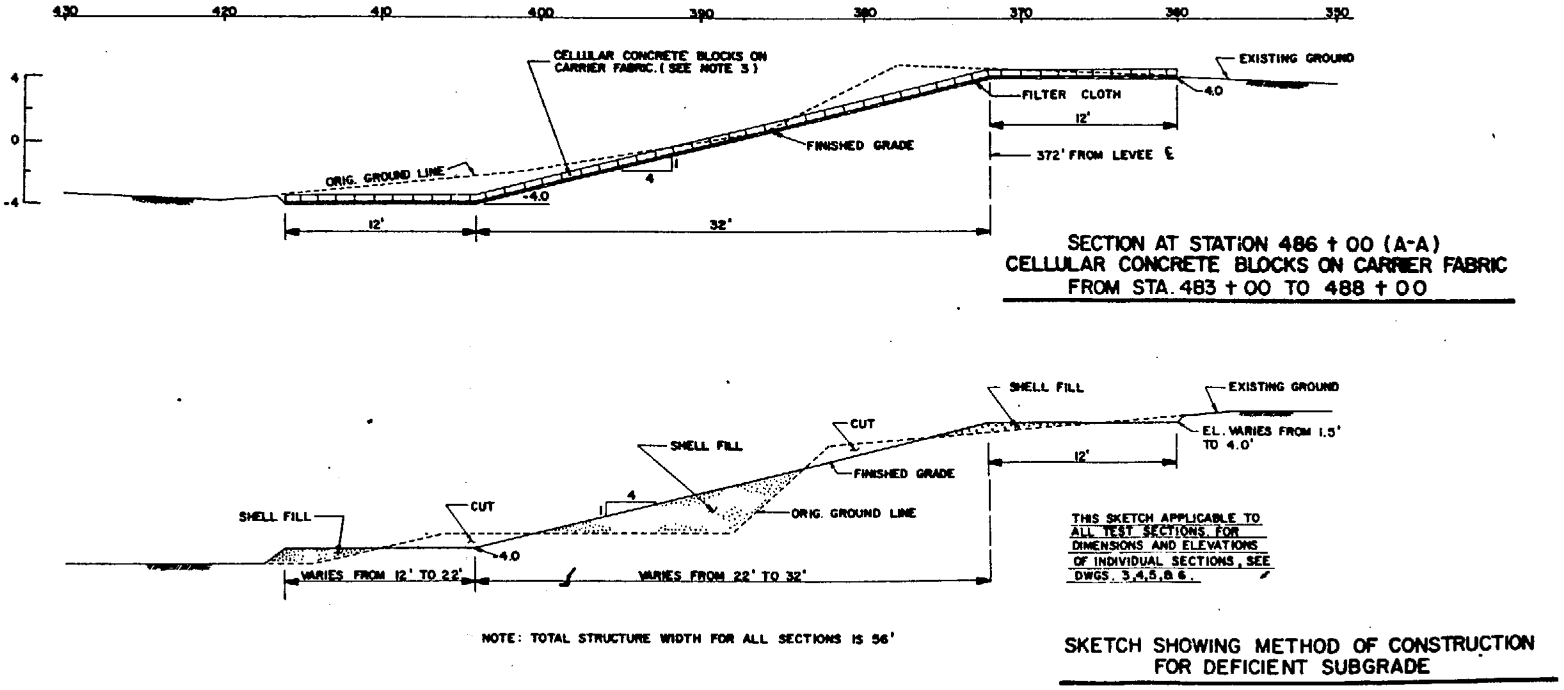
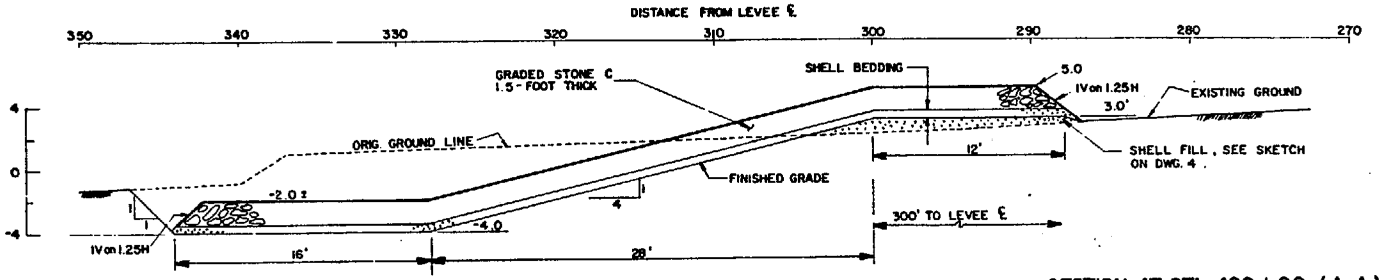
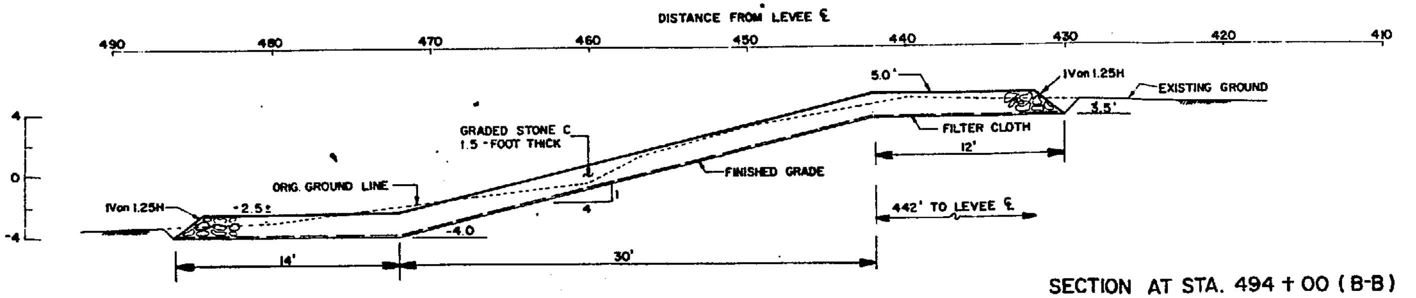


Figure 41. Design of test section 3, MRGO foreshore protection project (USACE 1982b).

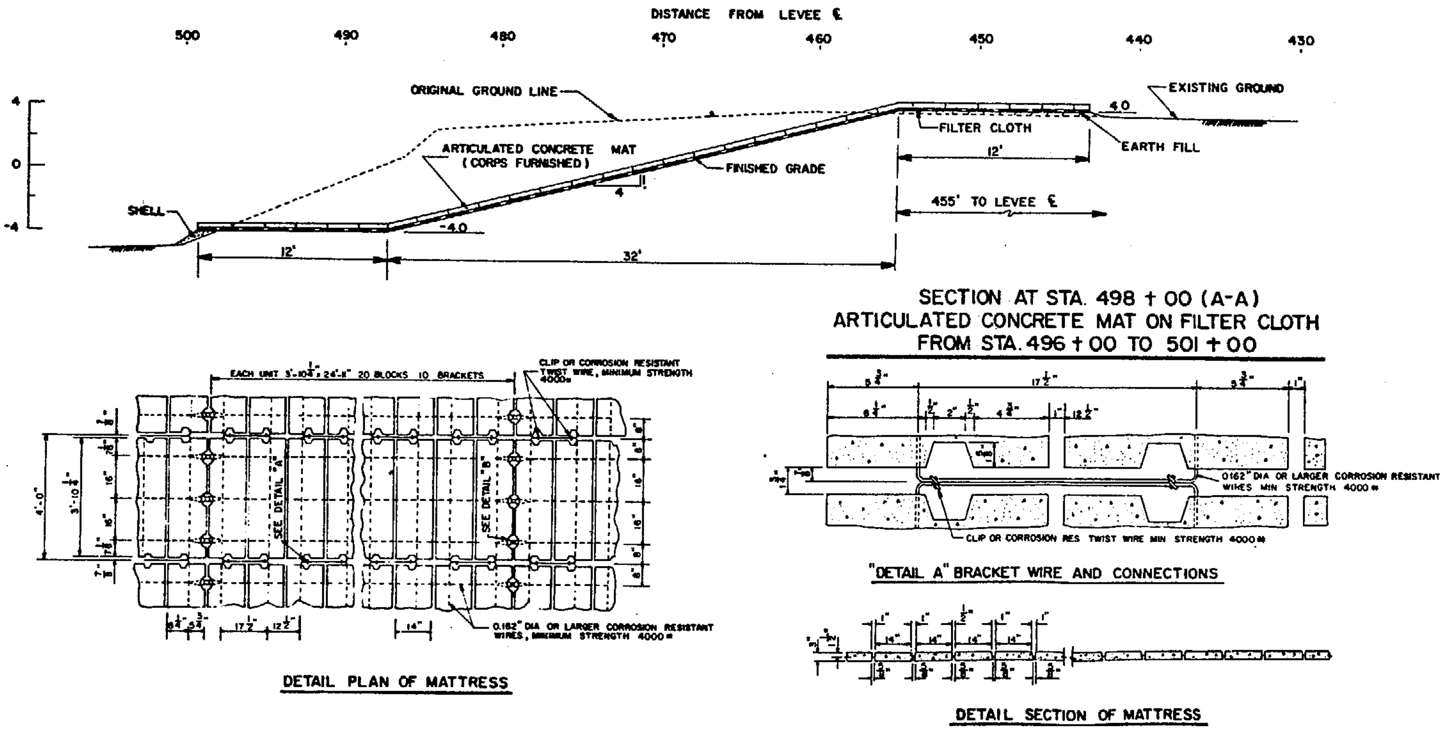


SECTION AT STA. 490 + 00 (A-A)
1.5 FEET OF GRADED STONE C ON 6 INCHES OF SHELL
FROM STA. 488 + 00 TO 492 + 00



SECTION AT STA. 494 + 00 (B-B)
1.5 FEET OF GRADED STONE C ON FILTER CLOTH
FROM STA. 492 + 00 TO 496 + 00

Figure 42. Design of test sections 4 and 5, MRGO foreshore protection project (USACE 1982b).



SECTION AT STA. 498 + 00 (A-A)
ARTICULATED CONCRETE MAT ON FILTER CLOTH
FROM STA. 496 + 00 TO 501 + 00

DETAIL PLAN OF MATTRESS

"DETAIL A" BRACKET WIRE AND CONNECTIONS

DETAIL SECTION OF MATTRESS

Figure 43. Design of test section 6, MRGO foreshore protection project (USACE 1982b).

Effectiveness

Six test sections were evaluated and only the 36-in layer of large stone was proven to be structurally successful. The foundation settlements of the stone sections ranged from 0.5 ft to 1.2 ft with the heaviest section having the smallest settlement. This is an indication of the variation of the materials on which the sections were built and does not allow for a comparison of the filter cloth and shell bedding. Sections 3 and 4, which utilized an 18-in layer of smaller class "C" stone, did not survive the conditions on the MRGO. The Corps estimated that 30% of the stone was displaced from the shell section. Portions of the filter cloth section were left completely void of stone. The Corps speculated that the filter cloth used was too impermeable and contributed to failure of the one section. Since the stone was displaced on both sections, it was apparently too small to resist the wave forces when placed loosely on the shoreline.

The two sections of light weight materials, interlocking concrete blocks on filter cloth, and articulated concrete mat on filter cloth, were both destroyed by ship waves. These two sections apparently failed in the same mode which is related to the hydrostatic pressures resulting from drawdown and the turbulence of the return flow. The Corps has speculated that the filter fabric used in the tests was too impermeable and did not allow relief of the back pressure, causing uplifting forces and eventual failure. Figure 44 shows the displacement and undermining which occurred on the failed mat section. The Corps also felt that neither the mats nor the blocks were heavy enough to hold down the filter fabric; however, no mention was made of the permeability of the armor materials contributing to failure. Upon observing the design of the mats it appears that this contributed greatly to the failure of the section. These mats are built from impermeable concrete which is 14 in wide and 4 ft long. When placed on top of the filter cloth, they greatly reduce the area of the filter through which water can flow, thus increasing the back pressures. Although the Corps did not furnish details of the interlocking block design, it is likely that this same effect led to failure.

Upon analyzing the Corps data it is apparent that none of the test sections would be suitable for use on the northeast shoreline. The 36-in layers of stone that were successful on the southwest shore would show massive settlements on the compressible marsh soils of the northeast shoreline. Construction would be extremely difficult since the shoreline is low and discontinuous. Finally, the cost of this type of

Figure 44. Photograph taken 27 March 1984 of failed test section 6, MRGO foreshore protection project.

protection is almost $300/ft ($1.5 million/mi). The 18-in layer of the smaller class "C" stone was more reasonable at about $150/ft, but it failed structurally and apparently cannot withstand the wave action. The interlocking block section was the most expensive of all and showed the worst performance. The cost of the concrete mats was intermediate; however, this section also failed.

Suggested Shoreline Protection Measures

Measure 1: Heavy Duty Plastic Membrane Bulkhead

Design

The first control measure proposes that a bulkhead be constructed using heavy duty plastic membrane, pilings, and fill material. Cross-sectional and front views of Measure 1 are shown in Figures 45 and 46, respectively. In addition, cellular concrete mat is proposed to protect the lower shoreline adjacent to the structure. On the landward side, rock would be placed along the base of the structure.

The plastic membrane which is being proposed is a black material which does not destruct under sunlight and is of sufficient rigidity to support backfill. Two rows of treated timber pilings will be driven along the shoreline approximately 4 ft apart, and the timbers themselves would be spaced approximately 4 ft apart in each row. It appears that 20-ft-long pilings would be sufficient in most areas although the stability would need to be checked in the field. It is recommended that the pilings be driven until the top is at approximately +3.5 ft NGVD. These two rows would be cross-tied with cable for additional support.

The plastic membrane is installed vertically along the inside of the two rows of pilings and is held in place by timber planks which are nailed across the top of the pilings. A fill material would be placed between the two layers of plastic membrane, forming the interior of the structure. Several possibilities exist for fill materials. The most available material would be dredged spoil from near the shoreline; however, this type of material may cause serious problems in construction for several reasons. First, the dredged material would have a high water content which prevents compaction. Second, because of the water contained in the dredged material, the construction process is likely to be much slower because the material would need to be placed,

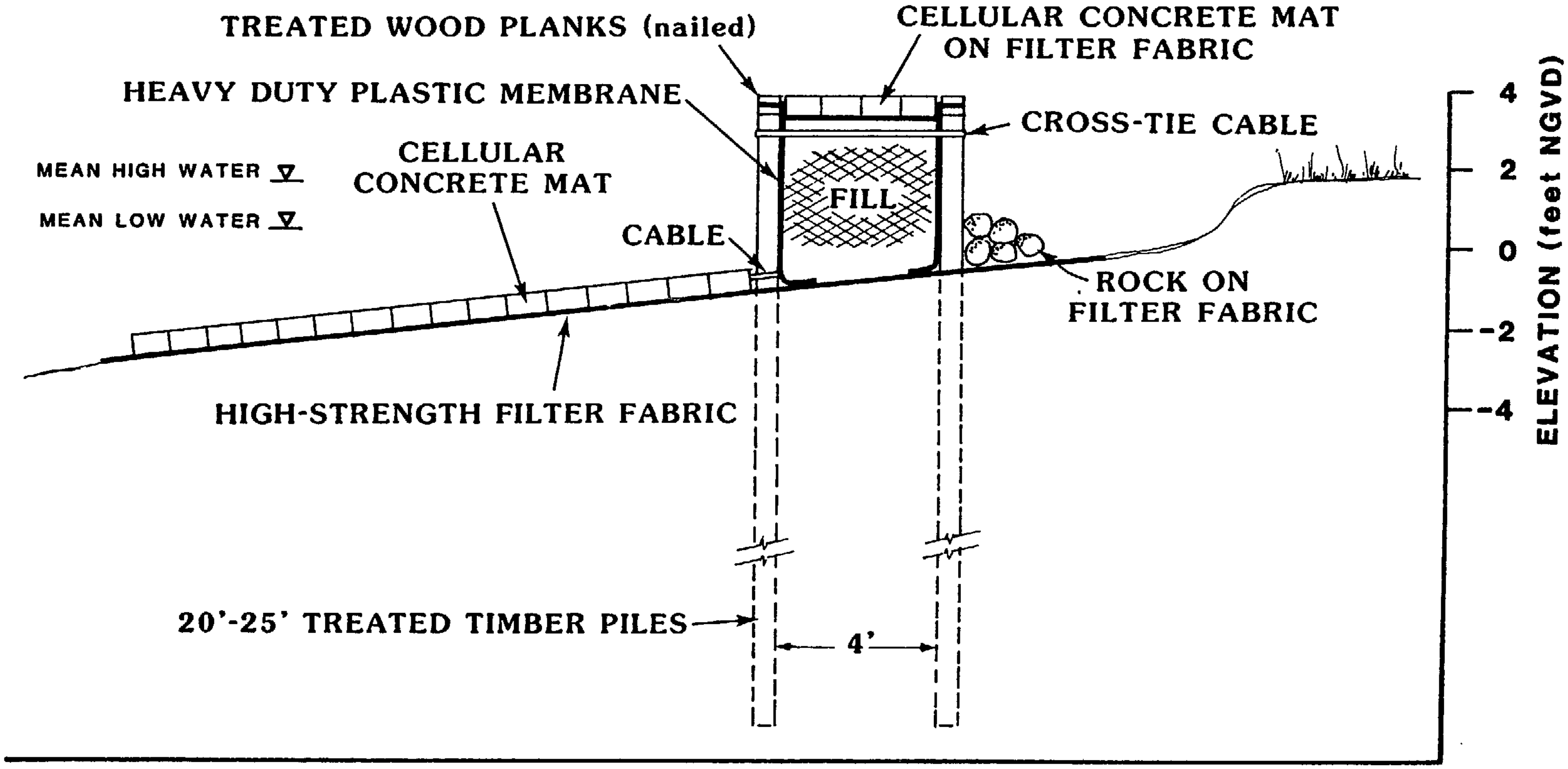


Figure 45. Cross-sectional design of suggested shoreline protection Measure 1: heavy duty plastic membrane bulkhead.

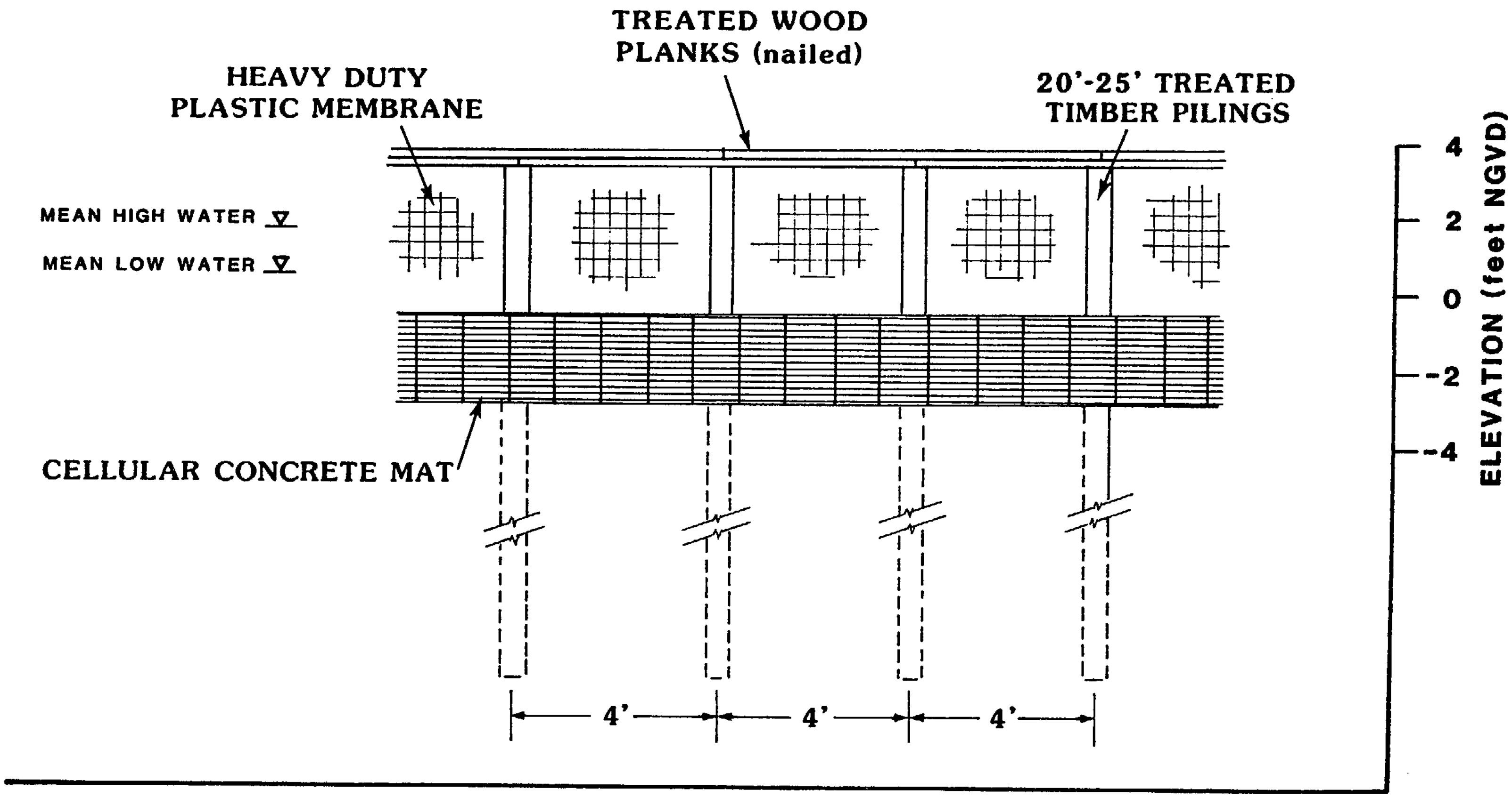


Figure 46. Front view design of suggested shoreline protection Measure 1: heavy duty plastic membrane bulkhead.

allowed to consolidate, and then more material added. Finally, the soils in the immediate area are marsh-type soils, which are generally inappropriate for backfilling. The best material to use would be clamshell, because it will not undergo a large amount of compaction after placement, and it is light-weight and readily available. A rock material could also be used, but it must be fairly small so that large void spaces are not formed. If earth material is used it is best if it is dry, coarse-grained soil.

The structure has a section of cellular concrete mat across the crest, which will prevent washout of the fill material. (Rocks could be used as an alternative.) The cellular concrete mat is also proposed to protect the lower shoreline in front of the structure. This material consists of precast concrete blocks which are approximately 1 ft square and weigh from 30 to 50 lbs. The blocks are held together by polyester cables (for marine applications) which allow the mat to shift and settle when in place and prevent the blocks from being dislodged. Also, the blocks have up to 25% open area, which allows water movement and prevents hydrostatic pressures from building up.

On the landward side of the structure, rock would be placed along the base to prevent the wave overwash from eroding under the structure. A high-strength filter fabric is proposed to be used between the marsh soil and the construction materials. This fabric performs several important functions. First, it separates the marsh soil from the construction materials, preventing the movement of materials down into the compressive marsh soil and thus preventing the excessive use of materials. Second, the fabric causes a uniform pressure distribution over the soil, limiting the amount of consolidation; so the filter fabric must be strong to prevent ripping and tearing. Finally, the filter fabric prevents the soil underneath from being washed out from below the construction materials.

Cost

The estimated cost of Control Measure 1 has been computed based on the approximate amounts and expenses of the construction materials. A breakdown of these costs is shown in Table 8. Items such as hardware, which are not of significant cost, have been ignored. It should be realized that these are very rough estimates of the amounts and costs of materials compiled to indicate the amount of funding which would be required in a shoreline stabilization project on the MRGO. The largest variable in this cost

Table 8. Estimated Cost for Control Measure 1.

Treated Timber Pilings at $37.50 each on 4-ft centers	$ 19
Heavy Duty Plastic Membrane 12 ft^2 at $1/$ft^2$	$ 12
Cabled Armored Mat 15 ft^2 at $2.50/$ft^2$	$ 38
Clamshell 0.6 yd^3 at $13/$yd^3$	$ 8
Treated Planks at $11.50 each	$ 4
High strength filter fabric 20 ft^2 at $25/$ft^2$	$ 5
Total Materials	$ 86 /linear ft
Estimated Labor and Equipment	$ 60
Total	**$146** /linear ft
	($770,880/linear mi)

analysis is labor and equipment. These costs vary according to the type and amount of equipment and labor used, as well as the speed at which construction proceeds. A variable estimate of $60/linear ft is presented based on completion of 50 ft per day. The material costs have also been presented as cost/linear ft so that they might be compared to other stabilization projects. The total cost of $146/linear ft is equivalent to approximately $0.75 million/mi.

Benefits

Light-Weight Materials

The materials used in Control Measure 1 were carefully selected to avoid excessive weight yet still have the rigidity to avoid washout. These types of materials are essential to having a structure which will survive for an extended time. If heavy materials are used, settlements will occur over time and the structure can be damaged and fail. Of further benefit is the fact that less settlement occurs and therefore fewer materials are needed in construction. Using high-strength filter fabric to underlie the materials will reduce settlements even further.

Minimal Excavation

Since much of the structure will be built in front of the shoreline, only minimal excavation will be necessary. The concrete mat can be laid on the lower shoreline without any preparation except removal of debris. The construction can therefore be performed from the MRGO without traveling on the marsh, preventing the further loss of marsh since heavy equipment movement would undoubtedly cause land loss.

Use of Cabled Mat

The cellular concrete mat proposed to be used has advantages over comparable materials. First, the mats are easily transported, as they can be placed on a flat barge and taken to the study area. Secondly, the installation requires only a hoist to lift the mats from the barge and lay them into position on the submerged shoreline. Installation is therefore quick as well as easy. Furthermore, the mats are flexible and will adjust to the shoreline contours and to any settlements which may occur.

Marsh Building

This control measure has an added attractiveness in that possibilities exist for the building of marsh. Most of the length of the structure will be built in front of the existing shoreline, resulting in enclosed, shallow water areas. At a future time dredged material can be placed in this area and marsh created. In some areas along the MRGO where the bench is shallow, it may be possible to reclaim significant amounts of marsh.

Stabilization of Pilings

The pilings which are used in the structure provide stabilization because they are embedded into a more stable layer that exists at approximately -10 ft NGVD. These pilings will prevent the structure from being dislodged laterally. Without stabilization from the lower soil layer, serious structural problems can occur with differential settlement. The pilings serve the additional function of holding the concrete mat in place.

Minimal Amount of Bulk Materials

This control measure utilizes only 0.6 yd^3 of bulk material/linear ft. This measure is extremely beneficial when transportation costs are considered, and advantageous because fewer materials must be placed, and labor and equipment time are saved.

Problems

Foundation Settlements

Although excessively heavy materials have been avoided in this control measure, some settlement will occur; the largest amount will be under the fill material (shell or earth). Foundation settlement does not occur entirely at once but rather over months or years. Since the amount of fill being used is not large, the settlements should not be large, probably not greater than 1 ft. The result of this settlement should not harm the structure; it will only cause the top of the fill to be lower than the pilings. But more fill material may eventually need to be added.

Structure Height

The plastic membrane which is being used is limited to approximately a 5-ft vertical height when used with the pilings. If the crest elevation is +3.5 ft NGVD, then the base must be no lower than -1.5 ft NGVD. This may require that the structure be placed at the shoreline in areas where the water is deep. However, field observations have indicated that in most areas there is a very shallow bench area in front of the marsh. More extensive surveys are required to determine the profiles along the shoreline and to identify areas where water depth may cause problems.

Measure 2: Armored Spoil Bank

Design

The second control measure proposes that an armored bank be constructed near the shoreline (Figure 47). The exact placement of structures in proximity to the shoreline for either Control Measure 1 or 2 would be determined on the basis of more extensive shoreline surveys. Structure placement will be limited largely by the depth of water and will also be controlled by the alignment of the shoreline and how much land may be desired for reclamation. Measure 2 is an alternative to Measure 1; however, many of the same construction materials are being used since these materials are most suited for this environmental application.

This second measure varies from the first in the that an inclined bank is being established rather than a vertical bulkhead. As in the first plan, treated timber pilings would be driven in a row along the shoreline with approximately 5 ft of spacing. An additional row of pilings installed landward would serve as anchors for support cables to reinforce the structure against water pressures built up during drawdown.

The heavy duty plastic membrane would be placed on the inside of the pilings and secured in place with wooden planks as before, forming the back side of the armored bank. The plastic membrane and pilings are being used to conserve materials and lower costs. Alternatively, the armored bank could be built symmetrically with a back slope identical to the front. However, the pilings should be installed regardless, because cellular concrete mat will be tied to the pilings to prevent the mat from sliding out of place.

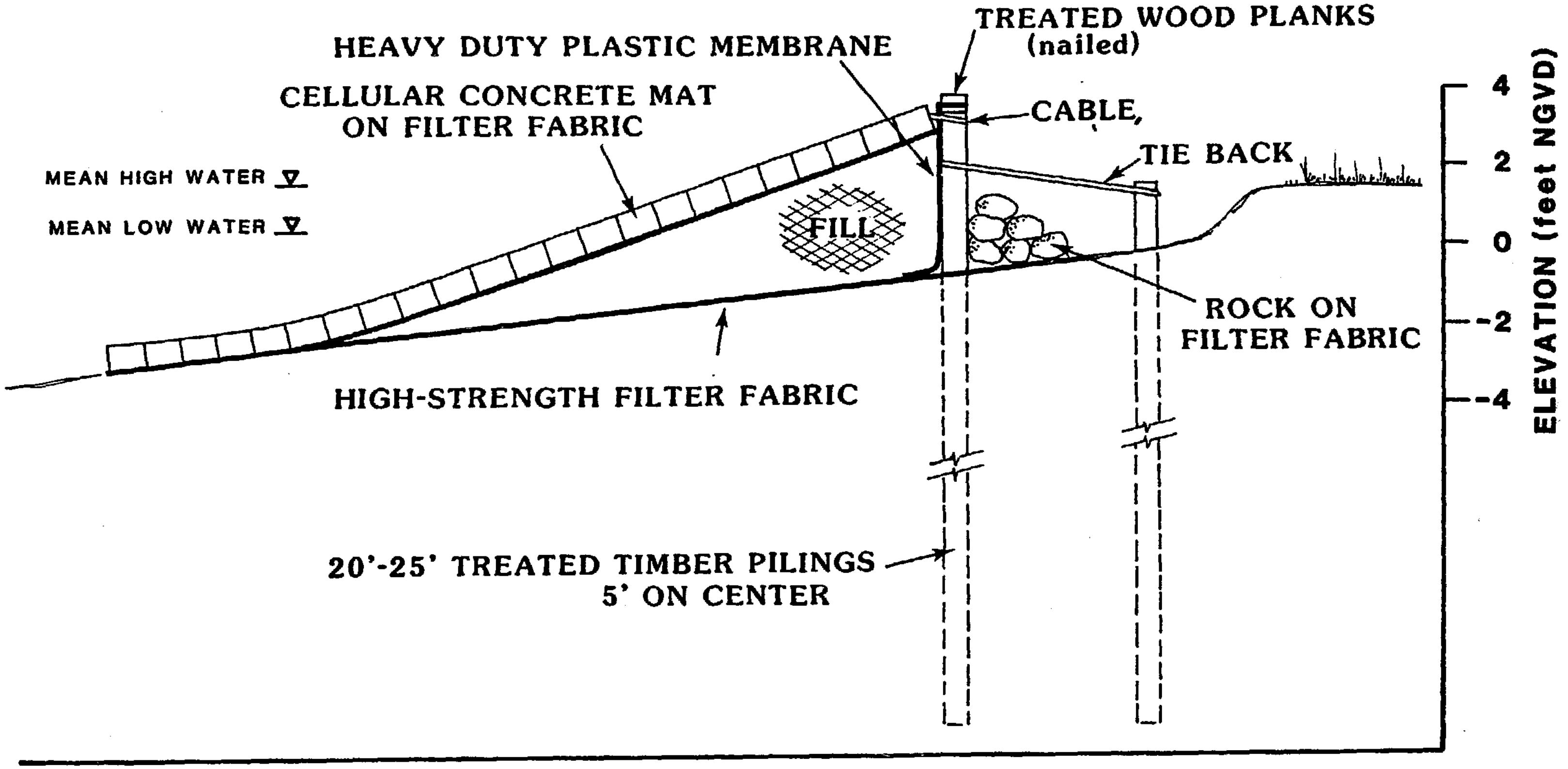


Figure 47. Cross-sectional design of suggested shoreline protection Measure 2: armored spoil bank.

Table 9. Estimated Cost for Control Measure 2.

Treated Timber Pilings at $37.50 each on 5-ft centers	$ 15
Heavy Duty Plastic Membrane 6 ft^2 at \$1/ft^2	\$ 6
Cabled Armored Mat 20 ft^2 at \$1 ft^2	\$ 50
High Strength Filter Fabric 20 ft^2 at \$.25/ft^2	\$ 5
Clamshell 1.2 yd^3 at \$13/yd^3	\$ 15
Treated Planks at $11.50	$ 2
Total Materials	$ 93 /linear ft
Estimated Labor and Equipment	$ 60
Total	**$153** /linear ft
	($807,840/linear mi)

Use of Cabled Mat

The same advantages described previously apply to this control measure. Because a larger width of mat is being used in this measure, the ease of transportation and placement becomes even more attractive.

Marsh Building

The same possibilities exist for creation of marsh as were mentioned previously. The structure would be placed at some distance from the shoreline and then this enclosed area could later be made into marsh.

Stabilization of Pilings

In this structure the pilings again are an advantage because of the support against lateral movement. Thus the structure will remain stationary and not dislodge by movement. As the foundation settles, the pilings will prevent the concrete mat from sliding out of place.

Problems

Foundation Settlements

Control Measure 2 is more subject to the settlement of the foundation because of the greater weight of the fill materials. The effects of this settlement on the structure are difficult to determine. As the fill material becomes lower in elevation, the cabled mat will settle accordingly, except near the crest of the structure where the mat is tied to the pilings. At this point, space may develop between the fill and the mat because the tieback to the pilings will prevent the mat from completely settling on top of the fill. A possible solution would be to tie the mat loosely to the pilings to allow settlement. However, if the mat moves too far away from the pilings the fill material may wash out from wave overtopping. Field tests would be the best solution to determining the settlement problems and how to best build the structure.

Bulk Materials and Placement

One major disadvantage with control Measure 2 is the greater amount of bulk materials that will be required. Both transportation costs and construction costs will increase as a result of using this amount of bulk material. It should be realized, however, that clamshell is being recommended. Additionally, the quantity of shell to be used is much less than the amount of rock the Corps used. The placement of the clamshell fill may, however, cause problems. It is proposed that the clamshell be dumped along the pilings so that a smooth slope will exist for placement of the mats. The clamshell may not form a slope as well as is expected, particularly since part of the slope will be submerged. Some forming may be required after placement to assure a uniform slope so that the mats may be laid as flat as possible.

Structure Height

The same problems exist with the allowable height of the structure as were presented for measure 1; the height is limited to approximately 5 ft because of the plastic membrane material being used on the backside. Surveys will be required along the bench area to determine the location of the structure.

Measure 3: Vessel Speed Limits

Design

There is no speed limit on the MRGO. The present speeds of oceangoing vessels range from 12 to 17 mi/hour, with an average speed of 14 mi/hour (data from Vessel Traffic Service, U.S. Coast Guard). These typical vessel speeds fall within the range of significant wave height, whereby the damaging transverse waves increase geometrically in proportion to vessel speed (see Chapter 4). If vessels on the MRGO reduce their speed, say to 10 mi/hour, the transverse wave phenomenon could be substantially reduced in magnitude, and thus erosion would be reduced.

There is a shared myth among laymen and some governmental agencies that large displacement vessels must travel at oceangoing speeds in order to maintain steerage. The United States Coast Pilot states: "it is understood, however, that ships must maintain sufficient headway [in the MRGO] at all times in order that the vessel can be controlled" (U.S. Dept. of Commerce 1983). In reality, ships on the MRGO do at times go "dead slow" and sometimes even come to "full stop." Dead slow is commonly selected in danger situations and when vulnerable shore facilities are passed (Hoobler 1984). Full stop conditions are sometimes met when a pilot is exchanged. It is true that steerage generally is improved with faster speeds, but it is entirely incorrect to suggest that oceangoing vessels cannot go "dead slow." Money is the overriding reason that ships travel as fast as possible: the faster they go, the quicker they get there. In fact, a vessel speed limit of 10 mi/hour has been imposed in at least one commercial channel situation, the Great Lakes connecting channels (USACE 1983a).

All oceangoing vessels have four forward engine speeds: Full Ahead, Half Ahead, Slow Ahead, and Dead Slow. The actual ship speed associated with each engine speed depends on vessel design and environmental conditions. Ships in the MRGO commonly travel at Full Ahead and Half Ahead, resulting in the common range of 14 to 17 mi/hour. Dead Slow is typically 5 mi/hour for bulk carriers and 10 mi/hour for large displacement container ships (Hoobler 1984). Large displacement container ships could not be forced to travel slower than 10 mi/hour. Bulk carriers could travel below 10 mi/hour, but given that they are smaller displacement vessels and thus producers of smaller waves, it may be prudent to suggest that they also abide by a 10 mi/hour speed limit. It is expected that the overall 10 mi/hour limit would effectively reduce wave heights to half their present average. Thus a 10 mi/hour speed limit would reduce shoreline erosion by approximately one half.

Cost

The cost of the speed-limit protective measure would fall squarely on shipping concerns. Typical oceangoing commercial vessels cost approximately $3,000/hour to operate (New Orleans Dock Board 1984). The typical transit through the study area (22.5 mi from Bayou Bienvenue to Bayou La Loutre) at the average speed of 14 mi/hour takes 1.6 hours to complete. In other words, it typically costs shipping $4,800 for each transit. If a 10 mi/hour speed limit were imposed, it would take 2.3 hours for a transit, and thus a cost of $6,900; the cost difference per ship is $2,100. Assuming an average of three oceangoing vessels a day (see Chapter 3), the daily increased shipping cost would be $6,300. In conclusion, the annual cost of a 10 mi/hour speed limit through the study area is $2,300,000. This cost could be reduced if the speed limit was imposed only in selected areas, such as in the soft marsh zones only.

Benefits

The direct benefit of a speed limit would be reduced wave activity and thus reduced shoreline erosion. It is expected that such a measure would reduce erosion by one half. A corollary benefit would be increased safety to small boats.

Problems

Erosion will not be completely checked; it will only be reduced. Further, the impact on shipping concerns may be significant, to the point that shipping companies may select to transit in other locations. Thus the MRGO, which is already a waterway fraught with economic problems, may be reduced to a totally uneconomical shipping channel.

Measure 4: Channel Enlargement

Design

Much of the extreme ship wave activity experienced on the MRGO is attributed to the design of the channel itself. The MRGO is a "restricted" waterway, given that the channel is only 500 ft wide and 36 ft deep. The restricted nature generates an exaggerated displacement effect during ship passage, causing transverse waves to be greatly enlarged (see Chapter 4). If the channel were deepened and widened (say to a 50-ft depth and a 750-ft width), the channel would be less of a restricted waterway and wave size would be proportionally reduced. In short, enlarging the channel reduces the erosive forces.

Cost

To be a viable measure, the whole MRGO would have to be enlarged. The MRGO canal, as it exists now, has cost the Federal government $406 million and the non-federal concerns $151 million (1979 dollars as defined by USACE 1981). Therefore, the total cost of the MRGO has thus far been $557 million. It is expected that an equal amount of money would be necessary if any sizeable channel enlargement were constructed.

Benefits

Erosion along the new shoreline after dredging would decrease, possibly by one half. Reduced maintenance dredging would be a corollary benefit, because with less erosion, less material would find its way to the channel bottom. A major boom to the shipping industry might also occur. Deeper draft vessels could make passage, and large ships could pass one another in safety.

Problems

This shoreline protection measure is, in a sense, contradictory to the goals of marsh preservation. In order to gain the advantage of reduced erosion rates, marsh must be excavated in order to build the channel. In the short term, heavy land loss will occur through dredging. Furthermore, erosion rates would only be reduced, not halted. Finally, the ecological disaster that occurred from saltwater intrusion caused by the present MRGO channel could only be enhanced by channel enlargement. In short, channel enlargement should not be seriously considered if the sole objective is to mitigate shoreline erosion.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This study has reviewed and researched numerous environmental parameters that affect the erosion on the northeast shore of the MRGO. The goal has been first to understand all causal factors affecting erosion, and second, to develop viable means for protecting the shore from future loss. The environmental analysis has involved such diverse subjects as geology, subsidence, salinity, water levels, tidal currents, vegetation, dredging, ship waves, and soils. Of the above, it has been determined that ship waves and soils are by far the most important factors in erosion of the shore.

Ship waves are variable according to size, speed, and design of ships. Marsh substrate, the dominant soil type along the MRGO, is extremely weak in nature and is, therefore, highly subject to erosion by the ship waves. Variations in soil types do exist though, and as such, erosion potential varies from 6 to 36 ft/year. Of the three soil types discussed--soft marsh, firm marsh, and swamp--soft marsh has proven to be the most extensive and most vulnerable to erosion. Firm marsh is intermediate in its ability to resist erosion, and swamp soil proves to be the least vulnerable to erosion.

Four protective measures have been developed for specific use on the MRGO. Measure 1, the heavy duty plastic membrane bulkhead and Measure 2, the armored spoil bank, are specific structural measures recommended for possible use. These measures were uniquely designed for the environmental conditions on the MRGO. They both incorporate deep seated pilings for a firm, suspended foundation and light weight materials for wave protection. These two measures are very similar in design. It is suspected that Measure 1 will be better suited because it incorporates less fill material, and thus less foundation-related problems. In reality, Measures 1 and 2 serve best as basic models from which other generically related measures can be formulated. In fact, a variety of measures should be designed and tested on the MRGO shore. Keep in mind that the Corps had six test sections on the southwest shore, and that four of these were judged to be complete failures.

With enough field testing, eventually a single structural measure will prove to be effective in erosion control. Then plans can be made to protect large sections of the MRGO. Soft marsh areas should be given high priority; firm marsh areas should be given secondary priority; and swamp shorelines, which are naturally stable, need not be protected at all.

Once large sections are emplaced, attention can then be given to the possibility of marsh restoration in the interior areas. Fill can be placed to marsh elevation in open bodies of water. The shoreline structure will allow fill material to be free from washout. Also, because the structures will retard saltwater intrusion, newly filled areas, as well as marshes that had not yet succumbed to land loss, will probably revert to less saline conditions.

Two nonstructural control measures have also been presented in this report. A vessel speed limit of 10 mi/hour (Measure 3) has been proposed as a viable method of reducing ship wave heights. Channel enlargement (Measure 4) is presented as a possible technique for reducing wave heights by altering the hydraulic properties of the present MRGO. It is not known whether either of these measures can be implemented given that they are very dependent on political and economic factors. Further, neither of these measures provides a complete solution, for shoreline erosion could only be reduced, not halted. The greatest value these measures present is realized only in concert with specific application of structural measures. For example, a vessel speed limit would be most successful if applied with a structural measure, thereby relaxing the design criteria for the structural measure and reducing its cost.

On a final note, it is conceivable that channel enlargement, if appropriately applied, could be used to the benefit of many concerns. The obvious shipping benefits are increased safety and greater economic viability. Erosion control could be enhanced in a variety of ways: (1) wave activity for each ship would be lessened; (2) the newly cut shore would be straighter, thus allowing for a more easily constructed shoreline control measure; and (3) dredge material would become available for marsh reclamation use.

The goals of this report have been both to define the causal factors of land loss in the region and to propose viable protective measures that would reduce land loss. The time has now come to select a measure (or measures), acquire funding for implementation, and proceed to protect the wetlands that remain.

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